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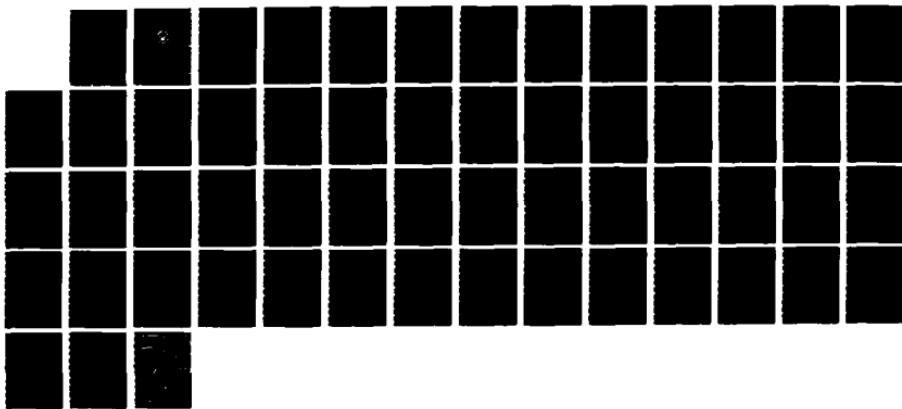
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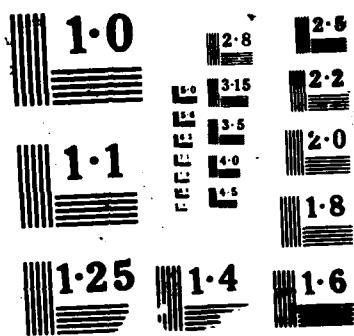
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CONTRACTOR REPORT

NUMERICAL COMPUTATION OF RING-SYMMETRIC
SPACECRAFT EXHAUST PLUMES

by

Joseph Falcovitz

January 1987

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Reproduction of all or part of this report is authorized.

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This report supplements report NPS72-86-003CR. It provides further details about the code JET and the numerical schemes on which it is based: inverse marching characteristic and semi-inverse marching characteristic (SIMA) schemes. The computational procedure is described in some detail. The principles of operation of the code JET are outlined, including a glossary of all major arrays, variables and subroutines. Finally, the full listing of the JET code is reproduced.

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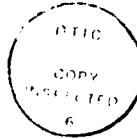


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NOMENCLATURE followed by units (if any) and CODE NOTATION (if any)

a	sound speed (m sec ⁻¹)
B	breakdown parameter [5,6,7]
C[±]	characteristic lines inclined at ($\theta \pm \mu$)
D	molecular diameter (hard spheres) (m)
M	Mach number
n	number density (molecules/m ³)
p	pressure (Pa)
S	coordinate along streamlines (m)
u	flow velocity (m/sec)
x	axial cartesian coordinate
y	radial cartesian coordinate
γ	specific-heat ratio (G)
η	length coordinate along fan characteristics (C^+) (m)
θ	inclination of flow velocity vector
λ_0	mean free path at stagnation conditions (m)
μ	Mach angle ($\sin \mu = 1/M$) (MU)
v	Prandtl-Meyer function (NU)
ξ	length coordinate along transverse (C^-) characteristic
σ	collision cross-section πD^2 (m ²) (SIGMA)
τ	molecular opacity (expected number of collisions by a fast invading molecule) (XI)
φ	collision frequency (sec ⁻¹)
ω	symmetry index (0 - planar flow, 1 - axisymmetric flow) (DELTA)
Γ	the fraction $[(\gamma + 1)/(\gamma - 1)]^{1/2}$
(v + θ)	Riemann invariant along C^- (RM)
(v - θ)	Riemann invariant along C^+ (RP)

INDICES

()₀	a specific point in the CRW (x_0, y_0) (Also : stagnation conditions)
()₁	nozzle exit conditions
()_L	limiting CRW characteristic ($p = 0$)
()_f	final CRW characteristic (boundary of numerical integration)
()_c	corner of CRW

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1. INTRODUCTION

In a recent report [1] a mixed numerical/analytical approach to the computation of a ring-symmetric spacecraft exhaust plume was presented. The numerical scheme had been implemented in a code named "JET" which is capable of generating whole-plume flow fields, while the analytic approximation is restricted to the ring-symmetric centered rarefaction waves (CRW) that flank the plume. The present report is intended to serve as a supplement to [1] in providing details on the computational scheme and the code JET.

The spacecraft exhaust flow (Fig. 1 of [1]) is idealized as a ring-symmetric steady isentropic expansion of an ideal gas. The nozzle lips are assumed sharp; the supersonic flow from the exit surface of the ring-nozzle is assumed uniform, and the background is considered to be perfect vacuum.

The standard scheme for computing such idealized ring-plumes is the classical (direct) method of characteristics [2] . At a preliminary phase of the present laser exhaust study, a code AXSYM [3] was written for computing ring-plumes using this method. A notorious shortcoming of the direct method of characteristics is that the solution grid is highly irregular, being formed by the (oblique) intersection of the C^+ and the C^- families of characteristic lines. We first encountered a difficulty with this grid while seeking a scheme for integrating the molecular opacity along a straight line [1] . This computation would have required rather complex coding for the geometry of intersection between a straight line and an irregular grid. It seemed preferable to opt for a computation scheme that would produce a more regular grid, even at the expense of some loss of accuracy. Such scheme is the inverse marching method of characteristics [4] .

Generally the marching in this type of scheme is in the downstream direction, i.e., the y direction in our case. Grid points are located on a succession of constant- y rows, thereby introducing a measure of regularity in the solution grid. Just two rows have to be stored in the computer core memory - the "old" row and the "new" row, whereas in the direct method of characteristics whole grid-image matrices are required to reside simultaneously in core memory.

The first version of the JET code was based on the inverse marching scheme given by Zucrow and Hoffman (Section 12-5 in [4]), where the flow variables were the *two cartesian velocity components*. The computation seemed accurate everywhere, except within the centered rarefaction wave (CRW). In an attempt to replicate a planar CRW (Prandtl-Meyer flow), the numerical solution exhibited an

instability : Mach number increased along the (low pressure) boundary characteristic line, rather than remain constant.

A *qualitative* explanation for this instability is the following. Flow gradients in a CRW are inversely proportional to distance from the corner, so that the inverse marching scheme gives rise to an amplification of interpolation errors at every marching step, leading to an apparently divergent (unstable) numerical solution. Increasing the order of interpolation from linear to cubic did not eliminate the instability.

Looking for a scheme that would replicate a planar CRW accurately, we tried the modified marching idea as presented by Zucrow and Hoffman for 1-D time-dependent flows (Sections 19-6(a) and 19-6(j) of [4]). In this scheme new grid points are determined by forwardly extending a "primary" family of continuous characteristic lines from old grid points. The primary family in a CRW is the characteristics fanning out from the corner (we assume it is the C^+ family). By choosing this modified scheme, the interpolation for trace points obtained from reversely extended C^+ lines was eliminated. However, the corresponding interpolation for the transverse C^- characteristics remained, and with it the aforementioned instability.

In order to replicate a planar CRW, we had to replace the flow variables by the *Riemann invariants* ($v \pm \theta$). In a C^+ planar CRW, the Riemann invariant ($v + \theta$) is uniformly constant, so that the interpolation in ($v + \theta$) due to reversely extending C^- characteristics introduces no error at all. This scheme, which we named SIMA (Semi Inverse Marching Algorithm), was indeed verified to replicate a planar CRW exactly, when implemented in the code JET.

The plan of this report is the following. In Ch. 2 we supplement the description of the numerical scheme given in Ch. 2 of [1] , by adding more details on the computational procedure. A description of the code JET is given in Ch. 3, and the code listing is reproduced in Ch. 4.

Note on symmetry :

The code JET has two symmetry options. When $\text{DELTA}=1$ a ring-symmetry is in effect; when $\text{DELTA}=0$, a planar symmetry is in effect. An axisymmetric jet exiting in the y direction from the same nozzle aperture along the x axis can readily be computed by replacing all terms in the code that correspond to $\sin(\theta)/y$ in the compatibility equations (2.1-1), by $\cos(\theta)/x$. In that case the coding is virtually unchanged, and the only care that should be exercised is for the difference equations for new grid points on or near the y axis. Also, all reference to the analytic approximation of the ring-symmetric CRW [1] should be deleted in this case, as it is designed specifically for ring-symmetry.

2. THE COMPUTATIONAL SCHEME

A basic description of the semi inverse (SIMA) and inverse marching schemes was given in Ch. 2 of [1]. We supplement this description by specifying the slightly modified definition of Riemann invariants in the code, and by giving information about some ancillary computations.

2.1 Riemann Invariants

The compatibility equations whose integration constitutes the numerical solution to the governing equations [1] are expressed in terms of the Riemann invariants as follows :

$$\text{Along } C^+ \dots (v - \theta)_4 = (v - \theta)_2 + \omega \sin \mu_{24} \sin \theta_{24} \Delta \eta / y_{24} \quad (2.1-1)$$

$$\text{Along } C^- \dots (v + \theta)_4 = (v + \theta)_1 + \omega \sin \mu_{14} \sin \theta_{14} \Delta \xi / y_{14}$$

The Riemann invariants $(v \pm \theta)$ are modified for convenience, by adding a constant to both v and θ . The new definitions of $v(M)$ and θ are :

$$v(M) = -\Gamma \arctan(\Gamma q) + \arctan(q)$$

$$q = (M^2 - 1)^{-1/2} \quad (2.1-2)$$

$$\theta \rightarrow \theta - \theta_L$$

Thus, in a Prandtl-Meyer flow with entry Mach number of M_1 , the modified values of both $v(M)$ and θ vanish as $M \rightarrow \infty$. As a consequence, in a C^+ Prandtl-Meyer flow the modified invariant $(v + \theta)$ vanishes uniformly. In this modified form, the computation of M from $v(M)$ is readily done by performing standard Newton-Raphson iterations (in RFUNC), using the derivative :

$$v'(q) = -(\Gamma^2 - 1) [(1 + \Gamma^2 q^2)(1 + q^2)]^{-1} \quad (2.1-3)$$

2.2 The Integration Scheme for a New Grid Point

The integration scheme has been sketched in Ch. 2 of [1]. It is performed in INVMAR for inverse marching points or in SEMINV for semi-inverse marching (SIMA) points. The computational scheme is specified via the following seven-step procedure :

INVMAR (Inverse Marching)

- (a) Grid : At this stage the new grid point has already been defined.
- (b) Predictor : Flow variables are the interpolated (linear nearest-neighbor) value on the old row for a point having the new grid x coordinate (x_4).
- (c) Centered variables : Denote the Riemann invariants by

$$RM = (v + \theta) \quad (2.2-1)$$

$$RP = (v - \theta)$$

then centered values for segments (1,4) and (2,4) (using code notation) are :

$$\begin{aligned} RM_{14} &= (RM1 + RM4)/2 & RP_{14} &= (RP1 + RP4)/2 \\ RM_{24} &= (RM2 + RM4)/2 & RP_{24} &= (RP2 + RP4)/2 \end{aligned} \quad (2.2-2)$$

All other centered flow variables are computed from the centered Riemann invariants by calling RFUNC.

- (d) Inverse Extension : old trace points x_1 , x_2 are evaluated from the geometrical relations

$$\text{Along } C^- \dots y_{\text{new}} - y_{\text{old}} = (x_4 - x_1) \tan(\theta_{14} - \mu_{14}) \quad (2.2-3)$$

$$\text{Along } C^+ \dots y_{\text{new}} - y_{\text{old}} = (x_4 - x_2) \tan(\theta_{24} + \mu_{24})$$

- (e) Interpolation : find Riemann invariants RM, RP at old trace points x_1 and x_2 through nearest-neighbor linear interpolation by calling INTERP.
- (f) Integration : Using the compatibility relations in finite-difference form (2.1-1) with segment-centered coefficients, compute iteration-updated values of Riemann invariants at new grid point.

- (g) Corrector : if values of Riemann invariants and old trace points x_1 , x_2 are not sufficiently convergent, resume the procedure at step (c) above.

SEMINV (Semi Inverse Marching - SIMA)

- (a) Grid : New grid point (x_4) is determined as part of the SIMA scheme at step (d) below.
- (b) Predictor : Flow variables are those of point (x_2, y_{old}).
- (c) Centered variables : Identical to step (c) above.
- (d) Semi-Inverse Extension : new grid point x_4 and old trace point x_1 are evaluated from the geometrical relations in Eq. (2.2-3) above.
- (e) Interpolation : find Riemann invariants RM, RP at old trace point x_1 through nearest-neighbor linear interpolation by calling INTERP.
- (f) Integration : Identical to step (f) above.
- (g) Corrector : Identical to step (g) above, except for replacing x_2 in the convergence test by x_4 .

2.3 Boundary Conditions

On the vacuum side the boundary conditions ($p=0$) can only be approximately implemented in a method of characteristics scheme. We do so by ending the computation on a certain "final" C^+ fan characteristic line that starts out with a sufficiently high Mach number M_f at the corner (typically $M_f = 34$). The marching computation of new grid points on the boundary C^+ characteristic via the SIMA scheme is identical to that of C^+ characteristics within the ring-symmetric CRW. It is noted that under this boundary scheme some outflow takes place through the boundary characteristic line, so that the total mass flow through a row $y = y_{new}$ decreases slightly as y_{new} increases.

At the nozzle exit the boundary conditions are assumed to be uniform outflow in the radial (y) direction with Mach number M_1 . At the nozzle lip, the SIMA integration starts out from a presumed planar CRW (Prandtl-Meyer flow) at the corner (i.e., the associate CRW in the terminology of Ch. 3 in [1]).

At the plane of symmetry ($x=0$) the boundary condition is simply $\theta=\pi/2$. However, this condition is implemented indirectly, by assuming that the flow at virtual grid points with $x < 0$ is a mirror-image of the flow at the corresponding $x > 0$ points. The reason is that when a new grid point of $x_4 = 0$ or of x_4 sufficiently close to zero is considered for inverse-marching integration, the inversely extended trace point (x_1, y_{old}) can be at $x < 0$. Considering the subtraction of θ_L from θ as in Eq.(2.1-2), the reflection rules are :

$$\begin{aligned} \text{RM} &\rightarrow \text{RP} + (\pi - 2\theta_L) \\ \text{RP} &\rightarrow \text{RM} - (\pi - 2\theta_L) \end{aligned} \quad (2.3-1)$$

where values on the left and right of the \rightarrow symbol correspond to values left and right of $x = 0$. This boundary condition is implemented in INTERP.

2.4 Continuum Breakdown Surface

As an informative option, the code JET can compute (in PLUMES) points on a surface of continuum breakdown [5,6,7], which is defined as a line of constant B , where B is given by :

$$\begin{aligned} B &= -(u/\varphi) \rho^{-1} (dp/dS) \\ \varphi &= 4(\pi\gamma)^{-1/2} \sigma n a \end{aligned} \quad (2.4-1)$$

When the standard isentropic relations for ρ and n in terms of M are substituted in (2.4-1), the flow speed is expressed as $u = Ma$ and the streamwise gradient of M is expressed in cartesian coordinates, we get :

$$\begin{aligned} B &= \lambda_0 (\pi\gamma/8)^{1/2} M^2 \left[1 + ((\gamma-1)/2)M^2 \right]^{1/(\gamma-1)-1} [M_x \cos\theta + M_y \sin\theta] \\ \lambda_0 &= (2^{1/2} \sigma n_0)^{-1} \end{aligned} \quad (2.4-2)$$

Note that the sign of B has been chosen as positive for expansion flows. This definition is preferred to taking an absolute value of the flow gradient, since it assures proper interpolation of B even if its spatial distribution goes through $B = 0$.

Due to the dependence of B on a spatial gradient, its numerical evaluation (see BREAK) is attributed to mid-grid points both in x and in y .

3. THE JET CODE

In this chapter we provide a concise description of the JET code according to its version at the time of the JET018 run. This description is intended as an aid in reading the code listing which is given in Ch. 4.

The plan of this chapter is as follows. Array variables that constitute the mainstay of the computational scheme are described in Section 3.1. Auxiliary array variables that are used primarily for processing the information generated by the numerical scheme, are described in Section 3.2, followed in Section 3.3 by a list of major parameters that control the computation (some of them also serve as run data). Finally, all subroutines are listed and described in Section 3.4.

3.1 Main Variables

The array variables used for the computational scheme are organized in two labeled COMMON groups. The first group /VECS/ is designed to hold two grid rows - the old row designated by suffix F and the new row designated by suffix N. The second group /CHARAC/ are characteristic-indexed arrays that hold information about continuous characteristic lines. This characteristic information is used in two ways : it is incorporated in the SIMA computational scheme for the CRW region, and it is used to store data for optional plotting of characteristic lines (see PLUMES and PRINT).

The basic organization is that the new arrays (suffix N) are those in which values are stored during the course of the marching computational procedure. At the end of each marching step, values are transferred from new arrays to old arrays (suffix F); this is done in MOVE. In the array listing below, we indicate in parenthesis the subroutine (or subroutines) in which that new array is defined.

/VECS/

XN(I)	x coordinate of grid point I. (GRIDN)
RMN(I)	modified Riemann invariant ($v + \theta$) at grid point I. (BEGIN, INVMAR, LOADC).
RPN(I)	modified Riemann invariant ($v - \theta$) at grid point I. (BEGIN, INVMAR, LOADC).
MN(I)	Mach number at grid point I (BEGIN, INVMAR, LOADC).
MUN(I)	Mach angle μ at grid point I. (BEGIN, INVMAR, LOADC).
TETAN(I)	true (unmodified) flow angle θ at grid point I. (BEGIN, INVMAR, LOADC).

BN(I)	value of breakdown parameter B at point I-1/2 (and at half a marching step back in y as well). (BREAK).
XTEMP(I)	used for auxiliary computation of I-1/2 grid points in PLUMES.

/CHARAC/

XCHARN(KC)	x coordinate of point on characteristic line number KC. (BEGIN, SEMINV, PLUMES).
YCHARN(KC)	y coordinate of point on characteristic line number KC. (BEGIN, SEMINV, PLUMES).
RMCARN(KC)	modified Riemann invariant ($v + \theta$) of point on characteristic line number KC. (BEGIN, SEMINV).
RPCARN(KC)	modified Riemann invariant ($v - \theta$) of point on characteristic line number KC. (BEGIN, SEMINV).
TCHARN(KC)	true (unmodified) flow angle θ at point on characteristic line number KC. (BEGIN, SEMINV).
MUCARN(KC)	Mach angle μ at point on characteristic line number KC. (BEGIN, SEMINV).
CSIGNN(KC)	sign of characteristic line number KC. It has value 1 for C^+ and value -1 for C^- . Note that upon reflection of a C^+ line from the symmetry plane ($x = 0$), the sign value is changed from 1 to -1. (BEGIN, SEMINV).
MCHARN(KC)	Mach number at point on characteristic line number KC. (BEGIN, SEMINV).
MCHARI(KC)	Mach number at Prandtl-Meyer's fan characteristic number KC at the corner. It is defined initially and is not changed during the run. (BEGIN).

3.2 Auxiliary Variables

In addition to the major arrays mentioned above, there are several groups of auxiliary arrays that do not affect the computational scheme, but are intended for informative processing of the results. These groups are /PLUME/, /IPLUME/, /THICKY/, /THICKX/, /GRP/. /PLUME/ is used to preserve points on special lines for later plotting (in a separate code). /THICKY/ and /THICKX/ are for storing values of radial (**y**) and lateral (**x**) molecular opacities. The group /GRP/ is used in conjunction with comparative computation of the ring-symmetric CRW flow according to the analytic approximation [1].

/PLUME/ (PLUMES, PRINT)

XPL(J,IPL) x coordinate at marching step J of special line number IPL.
YPL(J,IPL) y coordinate at marching step J of special line number IPL.

/IPLUME/ (PLUMES, PRINT)

KPL number of special lines computed in PLUMES.
ITYPL(IPL) index indicating the type of special line number IPL.

/THICKY/ (OPACY, PRINT)

XTH(J) x coordinate on boundary characteristic line at marching step J, from which radial opacity is integrated.
TH(J) radial opacity computed by y-integration from the boundary point defined by XTH(J) (up to current YN).

/THICKX/ (OPACX, PLUMES, PRINT)

YXI(JXI) y coordinate of printed row number JXI (the index JXI counts just rows that have been printed). The row to be printed next upon calling PRINT is the row having YF near YXI(JXI).
XI(I,JXI) lateral (x) molecular opacity [1] at point XF(I), for printed row JXI. It is obtained by numerically integrating the solution obtained from the JET computation (see OPACX).
XIPM(I,JXI) same as XI(I,JXI) except that the Prandtl-Meyer solution is used to estimate the flow at grid points XF(I).
XIGRP(I,JXI) same as above, except that the analytic approximation to a ring-symmetric CRW [1] is used to estimate the flow at grid points XF(I).
XIAPP(I,JXI) same as XIGRP(I,JXI) except that the numerical integration is replaced by an approximate closed-form expression [1].
XIF(I,JXI) stores grid points XF(I) of printed row JXI.

/GRP/ (PRINT, HMSET, MFUNC, HINTER, MATCH)

DMINV increment of inverse Mach number for array MHINV(I).
MHINV(I) inverse Mach number array (from 0 to 1/MEXIT), from which the H(M) function can be evaluated (HMSET).
HMV(I) values of the H(M) function evaluated by numerical integration. It is used to compute this function by interpolation. (HMSET, HINTER).

3.3 Major Parameters

Parameters that define and control a particular run (such as the maximum y for the marching computation, the number of grid points on a row and many more) are defined in INIDAT. (The code JET has no input file and no READ statements). The major control parameters are grouped in /PAR/ (floating point) and in /IPAR/ (integers); thermodynamic data are grouped in /STAG/.

We indicate in the listing the subroutines in which the labeled COMMON group or a particular parameter is defined (or sometimes referred to).

/PAR/ (INIDAT)

MEXIT	nozzle exit Mach number (M_1).
MFIN	Mach number of the final (boundary) CRW characteristic at the corner (M_f).
YMAX	maximum value of y for the marching scheme. When $YF \geq YMAX$ the run is terminated.
DY0	initial marching step.
DY	current marching step.
DYNEXT	next marching step (YSTEP).
STAB	stability coefficient for marching step (STAB.LE.1). (See YSTEP).
DELTA	symmetry index. $\text{DELTA} = 0$ for plane symmetry; $\text{DELTA} = 1$ for ring-symmetry.
PSI1	angle of Prandtl-Meyer fan characteristic at exit conditions (measured from x axis).
PSIF	angle of final (boundary) Prandtl-Meyer fan characteristic.
SIGMA	collision cross-section (σ).
FRACG	the number of intervals initially allocated to the CRW fan is a FRACG fraction of the total number of intervals (KF0-1). (see BEGIN).
EPSIL	convergence parameter (small number). (INVMAR, SEMINV).
TETLIM	flow angle (from x axis) of the limiting ($p = 0$) velocity vector of the flow at the lip-centered Prandtl-Meyer fan.
TETSYM	PAI-2*TETLIM for reflection transformation (see INTERP).

/IPAR/ (INIDAT)

JMAX	maximum number of marching steps. If $J \geq JMAX$ run is terminated.
KF0	initial (and maximum) number of grid points in a row.
KF	current number of grid points in the old row.
KN	current number of grid points in the new row.

ITER0	maximum number of iterations for the integration of the compatibility relations (see INVMAR and SEMINV; also used in RFUNC, PLUMES).
IM, IP	search indices for interpolation subroutine INTERP. (see INVMAR, SEMINV).
J	current row index (also index of a marching step).
KF2	defined as 2*KF; not used in present version.
IDEL, JDEL	increments for printing grid point I and row J (see PRINT).
JYXI	number of rows to be printed in a run.
JXI	index of printing row, to be printed next (see PRINT).
ILEAD	index I at the first grid point on current new row, where the SIMA integration commences. Initially this point corresponds to the leading characteristic of the CRW. (see GRIDN, BEGIN).
ILEADF	value of ILEAD for current old row.
KCLEAD	index in the characteristic array for the characteristic line that corresponds to the new grid point I = ILEAD (see GRIDN). Initially KCLEAD = 1.

/STAG/ (INIDAT)

RHO0, NO	stagnation density and number density.
P0, T0, A0	stagnation pressure, temperature and sound speed.
MDOT1	mass flow rate from ring-nozzle (only from the $x > 0$ half). (See PRINT).

/ICHARA/ (BEGIN)

KCHARP	number of C^+ characteristic lines for which data is stored (either for SIMA computation or for subsequent plotting).
KCHARM	number of C^- characteristic lines for which data is stored (only for subsequent plotting).
KCHAR0	total number of characteristics for which data is stored, i.e., KCHAR0 = KCHARP + KCHARM.

3.4 Description of JET subroutines

MAIN PROGRAM

The main program performs two functions. The first section (up to statement 1) is the initial set up; it is performed just once. The second section is the marching loop with the step index J. This program can be read as a flow chart of the overall computational procedure.

INIDAT is for setting up run data. In BEGIN the initial conditions for the marching computation are set up. A single marching step is performed by calling MARCH, and the loading of new row vectors into old row vectors is done by calling MOVE. The call to YSTEP is for the first computed marching step. All remaining calls are for informative tasks (see HMSET, BREAK, OPACY, PLUMES, PRINT). Run is terminated when either YF.GE.YMAX or when J.GE.JMAX.

NOTE ON EXEC : The only special feature in the EXEC is retaining the output unit 7 file for optional post-plotting. The printed output (unit 6) is the system's standard (default).

INIDAT

Initial data definition and preliminary data computations. The data is defined by statements rather than by reading an input file. The meaning of major parameters was described in Section 3.3 above. User is invited to modify the data definitions, particularly of run-control parameters such as YMAX, JYXI and YXI(JXI) (for printing JYXI selected rows).

BEGIN

Here all initial values (prior to beginning of marching schemes integration) are loaded into all major computational arrays (Section 3.1). Also, values of the key integer parameters KCHARP, KCHARM, KCHAR0, ILEAD, KCLEAD and KF are defined.

In the first loop (loop 1) we define an initial family of C^+ characteristic lines for the lip-centered CRW, by storing the Mach number of the Prandtl-Meyer fan characteristics in the array

MCHARI(KC). Note that the fan characteristics are generated at equal RP intervals, since the flow variables are RM and RP. However, a different division might also be acceptable.

The next step is the definition of initial values for all characteristic arrays, first the C^+ arrays (loop 2), then the C^- arrays (loop 21). The C^- characteristic lines are needed just for informative output (post-plotting), so the present version contains just one C^- line. The user may modify that.

The remaining grid points (altogether KF0 grid points are initially available) are uniformly distributed across the nozzle opening, and the row arrays are loaded with the corresponding nozzle-exit flow variables (loop 3).

PRINT

The main task of this subroutine is the printing of flow variables at grid points of selected rows. The printing of a row is selected when YF is close to a predefined array YXI(JXI). Following the printing, JXI is updated by adding 1.

For comparison, additional flow variables are printed for each row. These are computed from the analytic approximation to a ring-symmetric CRW [1], by calling MATCH. Also, lateral molecular opacities of various kinds of approximation are computed by calling OPACX, and are printed for each grid point within the CRW.

Following the row printing (statement 120), arrays intended for post-processing (plotting of special lines) are printed and subsequently written on output unit 7. This is done once per run, just before run termination.

FIN

This subroutine is called when an error is encountered, in order to terminate the run. Note that the run is terminated by deliberately introducing an error of computing $SQRT(-1)$, which is done in order to trigger the printing of calling sequences by the operating system.

MARCH

This subroutine performs a single marching step by calling the proper computational subroutines at an appropriate sequence. It can be read as a flow chart of the entire computational scheme. First the segment of the new row suitable for SIMA computation is calculated by calling SEMINV. Then new grid points for that part of the new row for which inverse marching integration is to be performed, are generated by calling GRIDN. The results of the SEMINV computation, which were stored in characteristic arrays, are now loaded into row arrays by calling LOADC. Finally, the computation of the new row is completed by calling INVMAR which computes the flow at the remaining grid points by the inverse marching scheme.

INVMAR

This is one of the two central subroutines for computing the flow at new grid points (the other is SEMINV). Here the inverse marching scheme is used. The computational procedure follows the seven-step description given in Section 2.2 above. Note that the initial value of the search indices IM and IP is not redefined at each call to INTERP, since it is assumed that IM and IP do not change much at consecutive calls to INTERP, so that search efficiency is enhanced by not starting the search from an arbitrary point (such as either end of the row).

SEMINV

This is the subroutine performing the SIMA scheme for computing the flow at new grid points located along continuous characteristic lines of the lip-centered CRW (at prescribed y-marching steps). The essence of the computational procedure of this subroutine was given as a seven-step description in Section 2.2. The same remark about IM given in the preceding INVMAR description applies here as well.

The main loop (100) is over all characteristic lines, including some C^- lines in addition to the C^+ lines. Thus, the array CSIGNF(KC) is used to get the appropriate expressions for either C^+ or C^- characteristics. It is noted that while normally the characteristic segments through points 1 and 2 are C^- and C^+ respectively, this is reversed when a C^- rather than a C^+ line is computed via the SIMA scheme. In this case, which is characterized by having CSIGNF(KC).LT.0, the Riemann

invariants integrated along segments (1,4) and (2,4) are interchanged. This is done in the few statements just preceding and following statement 21.

An additional capability of this subroutine is to treat a change of a C^+ characteristic line into a C^- line upon reflection from the symmetry plane ($X = 0$). This is done by first computing a new grid point having $X4.LT.0$, and then changing its sign after setting $CSIGNN(KC) = -1$ (statements just preceding statement 30). It is also possible to skip the computation of a particular characteristic by setting $CSIGNN(KC) = 0$. This feature is not exploited in the present version.

Finally, we note that not all characteristic lines computed here are part of the marching flow computation. Only those with indices KC between KCLEAD and KCHARP are. All other characteristic lines are computed just for informative purposes (post-plotting).

RFUNC

Here M, MU, TETA are computed from the two Riemann invariants RM, RP. The computation of M is performed by a Newton-Raphson iteration using Equations (2.1-2) and (2.1-3) given in Section 2.1 above.

INTERP

This subroutine starts by finding through a search procedure the grid interval (I, I+1) that contains a given point X. Then the Riemann invariants are computed for this point by linear interpolation, and returned in RM, RP. Note that X may be negative, which accounts for the relatively elaborate search logic in the determination of I, and for the reflection transformation (as in Eq. (2.3-1) above) preceding the last two statements of the subroutine.

INTERX

This interpolation routine performs an inverse task to that of INTERP, in that it finds the point X0 that corresponds to a given linearly interpolated value of the flow variable VAR0. It is used in PLUMES to compute the location of a breakdown surface point on a new row of x-centered and y-centered grid points.

BREAK

This subroutine computes the new breakdown parameter array BN(I). The computation is based on the description given in Section 2.4 above.

OPACY

Here the radial (Y) molecular opacity array TH(J) is computed. At each marching step J, a new boundary grid point XTH(J) is added, then the radial opacities at all preceding boundary points are updated by adding the contribution of the gas layer between the current old and new rows. Note that since grid points on adjacent rows are not located on equal-X columns, this procedure requires X-interpolation by calling INTERP.

PLUMES

This is a user-defined subroutine, where up to 10 special lines can be computed and subsequently retained on output unit 7 for post-processing (plotting). The type of the line ITYPL(IPL) and a parameter VPL(IPL) that defines the line, are computed through user-inserted statements in the section preceding statement 2000. Then an additional point on the current new row is computed for each line type. The available types are clearly stated in comments. Note that characteristic lines have already been computed in SEMINV using the SIMA scheme, regardless of whether they are part of the solution grid to the flow field, or are just computed for informative purpose. It is the user's choice which of these lines (if any) are to be saved in the /PLUME/ arrays for subsequent post-processing (plotting).

GRIDN

This subroutine computes the grid points in that segment of the new row for which the flow is computed by the inverse marching scheme (in INVMAR). Initially, this segment extends from $x = 0$ to the new row grid point which lies on the leading characteristic of the lip-centered CRW. However, since the leading characteristic is reflected from the symmetry plane ($x = 0$) at some point, this segment steadily shrinks in size as the marching proceeds. The remedy is to declare the next-to-the-

leading characteristic line ($KC = 2$) as the beginning of the segment for SIMA integration, by setting $KCLEAD = 2$. This process of increasing $KCLEAD$ is repeated whenever it is deemed necessary. The criterion in the present version for the minimal $KCLEAD$ is that the inverse-marching segment should be at least twice $DX1$ - the average CRW grid interval (loop 1, the two statements following $DX1 = \dots$). Also, $ILEAD$ is redefined for each row according to $XLEAD/DX1 + 2$ in order to achieve a row of relatively uniform grid intervals throughout. The result is that the number of grid points in a row is initially $KF0$, but eventually it decreases due to both increase of $KCLEAD$ and decrease of $ILEAD$.

YSTEP

In this subroutine the next marching step $DYNEXT$ is computed at the end of the current marching step. It is defined as the smallest step obtained by forward intersection of C^- and C^+ characteristics from adjacent grid points. Note that the actual value of $DYNEXT$ is reduced by a "stability" factor $STAB$, and that ΔY is also limited by the growth-rate factor DDY and by $DYMAX$ (see MAIN PROGRAM).

MOVE

Here old row arrays (loop 1) and old characteristic arrays (loop 2) are loaded with values of flow variables from corresponding new arrays, in preparation for the next marching step. As a result of this organizational feature, informative computations (e.g. BREAK, OPACY) that require both new and old rows, have to be performed prior to calling MOVE.

OPACX

Here lateral (X) opacities that correspond to the number of expected collisions of a fast molecule invading the CRW in the $-X$ direction, are computed. All opacities, except $XIAPP(1)$, are computed by numerical integration. In loop 1 we compute the opacity contribution of the segment lying just outside the computational boundary characteristic (MFIN), assuming a Prandtl-Meyer flow. This additional opacity is denoted $XI0$. If the flow is ring-symmetric, $XI0$ is recalculated using the analytic approximation [1] to estimate the flow field at the fringes of the ring-symmetric CRW (see also the closed form expression for τ in [1]).

The computation of opacity arrays starts after statement 14. First, the opacity at each grid point is set to XI0. Thus, even though the numerical flow computation does not include the fluid outside the boundary characteristic line, the opacity integration includes an estimate of that "missing" part, i.e., of XI0. In typical case computations of a ring-symmetric CRW [1] we found that the maximum value of XI0 was about 0.16., which indicated that as far as interaction with invading ambient molecules is concerned, the approximation MFIN = 34 was a reasonable substitute for MFIN = ∞ .

The next step is the computation by numerical integration of three approximations to the lateral opacity : XI(I,JXI), XIPM(I,JXI), XIGRP(I,JXI). (Note that when the flow is ring-symmetric, the approximation XIPM(I,JXI) obtained by assuming a Prandtl-Meyer flow is usually grossly exaggerated). The opacity XIGRP(I,JXI) is based on the analytic approximation to a ring-symmetric CRW [1], and is reasonably close to XI(I,JXI) which is obtained from the numerical solution to the flow field. Finally, a simplified closed-form integration of lateral opacity [1] is computed as XIAPP(I,JXI) (loop 3). Thus, the quantitative difference between XI(I,JXI) and XIGRP(I,JXI) is an indication to the degree of accuracy achieved by the analytic approximation to a ring-symmetric CRW [1], while the difference between XIGRP(I,JXI) and XIAPP(I,JXI) indicates the level of error introduced by the closed-form integration of lateral opacity [1].

LOADC

Here flow variables of new grid points computed via the SIMA scheme (SEMINV) are loaded into new row arrays from corresponding characteristic arrays.

NUFUNC

This function computes the modified $v(M)$ value as given by Eq. (2.1-2). Note that presently NU0 = 0 (see INIDAT).

HMSET

This subroutine is called just once from the MAIN PROGRAM. Its task is to set up the arrays in /GRP/, so that the function $H(M)$ [1] can be evaluated by interpolation (in HINTER). There is also an informative printout of various derivatives (see Ch. 3 of [1]) generated in this subroutine.

MFUNC

This subroutine is called by HMSET in order to compute functions of Mach number that serve in the computation of $H(M)$. The output variable F is the integrand for the integration leading to $H(M)$.

HINTER

This subroutine computes $H(M)$ by linear interpolation in inverse Mach number, using the /GRP/ arrays computed in HMSET.

MATCH

This subroutine is called from PRINT to compute the Mach number according to the analytic approximation of a ring-symmetric CRW [1], for point (YF,XF(I)). M0B is the associate Mach number $M(0,\beta)$, which is preserved in the array MCHARI(KC) for all CRW characteristics that are used in the SIMA computation. Hence the Mach number $M(\alpha,\beta)$, denoted by MAB can be computed directly from the analytic approximation [1] to the area function at (YF,XF(I)) by calling AREAF. Since typically $M(0,\beta)$ is not known, we also compute the Mach number via the inverse-problem procedure [1], denoting the resulting Mach numbers by suffix I: M0BI for $M(0,\beta)$ and MABI for $M(\alpha,\beta)$. The inverse-problem iterative procedure [1] is performed in loop I, resulting in M0BI. From M0BI the value of MABI is computed through the area function approximation as for MAB above.

AREAF

This subroutine computes the Mach number M that corresponds to the area function F (Eq. (3.2-1) of [1]). The computation is done by Newton-Raphson iterations, and it has been found to converge when $M.GT.1$ (and when $M - 1$ is not much smaller than 1).

4. THE JET CODE LISTING

```

C$OPTIONS LIST
C JET018          JET0001
C "JET" A SEMI-VERSE MARCHING CHARACTERISTICS METHOD FOR RING JETS. JET0002
C USING RIEMANN INVARIANTS RM=(NU+TETA), RP=(NU-TETA) AS FIELD JET0003
C VARIABLES.          JET0004
IMPLICIT REAL*8(A-H,L-Z,$)          JET0005
REAL*4 XPL,YPL          JET0006
COMMON /PLUME/XPL(1002,10),YPL(1002)          JET0007
COMMON /IPLUME/KPL,ITYPL(10)          JET0008
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),          JET0009
1   TETAF(101),BF(101),          JET0010
2   XN(101),RMNC(101),RPN(101),MN(101),MUN(101),          JET0011
3   TETAN(101),BN(101),XTEMP(101)          JET0012
COMMON/THICKY/XTH(1002),TH(1002)          JET0013
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF          JET0014
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)          JET0015
1   ,XIAPP(101,20),XIF(101,20)          JET0016
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0017
1   G16,G17,G18,G19,G20          JET0018
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,          JET0019
1   STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,          JET0020
2   TETSYM,TETLIM,DDY,DYMAX          JET0021
COMMON /STAG/RHOO,NO,P0,T0,A0,MDOT1          JET0022
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,          JET0023
1   KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD          JET0024
COMMON /ROW/YF,YN,DXF,DXN          JET0025
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),          JET0026
1   RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),          JET0027
2   TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),          JET0028
3   CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),          JET0029
4   MCHAR(92)          JET0030
COMMON /ICHARA/KCHARP,KCHARM,KCHAR0          JET0031
COMMON /GRP/DMINV,MHINV(101),HMV(101)          JET0032
COMMON /IGRP/KHM          JET0033
COMMON /IGRP/KHM          JET0034
C
101 PRINT 101          JET0035
FORMAT('1')          JET0036
J=1          JET0037
IF(J.EQ.1) STOP          JET0038
CALL INIDAT          JET0039
PRINT 101          JET0040
CALL HMSET          JET0041
PRINT 101          JET0042
CALL BEGIN          JET0043
CALL MARCH          JET0044
CALL OPACY          JET0045
CALL PLUMES          JET0046
CALL PRINT          JET0047
J=2          JET0048
CALL PLUMES          JET0049
CALL MOVE          JET0050
CALL OPACY          JET0051
CALL PRINT          JET0052
CALL YSTEP          JET0053
J=J+1          JET0054
1  DY WAS DETERMINED BY THE PREVIOUS CALL TO GRIDN.          JET0055
DY=DMIN1(DYNEXT,DY*DDY,DYMAX)          JET0056
C INTEGRATE BY ONE Y-STEP          JET0057
CALL MARCH          JET0058
C BREAKDOWN PARAMETER (BF(I)).          JET0059
CALL BREAK          JET0060
C SPECIALLY DESIGNATED LINES (FOR PLOTTING).          JET0061
CALL PLUMES          JET0062
C STORE NEW LINE (N) IN OLD LINE (F).          JET0063
CALL MOVE          JET0064
C COMPUTE RADIAL MOLECULAR OPACITIES          JET0065
CALL OPACY          JET0066
C Y-STEP IS VARIABLE, SO JMAX IS USED AS END-OF-RUN CRITERION.          JET0067
IF(YF.GE.YMAX) JMAX=J          JET0068
C PRINT FIELD AT MOST RECENT Y.          JET0069
CALL PRINT          JET0070
C NEXT Y-STEP.          JET0071
JET0072

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CALL YSTEP JET0073
IF(J.LT.JMAX) GO TO 1 JET0074
STOP JET0075
END JET0076
INIDAT

SUBROUTINE INIDAT JET0077
C SUBROUTINE NUMBER 1 JET0078
IMPLICIT REAL*8(A-H,L-Z,$) JET0079
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0080
1 TETAF(101),BF(101), JET0081
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET0082
3 TETAN(101),BN(101),XTEMP(101) JET0083
COMMON/THICKY/XTH(1002),TH(1002) JET0084
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF JET0085
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET0086
1 ,XIAPP(101,20),XIF(101,20) JET0087
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0088
1 G16,G17,G18,G19,G20 JET0089
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0090
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET0091
2 TETSYM,TETLIM,DDY,DYMAX JET0092
COMMON /STAG/RHO0,NO,PO,TO,A0,MDOT1 JET0093
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET0094
1 KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET0095
COMMON /ROW/YF,YN,DXF,DXN JET0096
C PAI=4.D0*Datan(1.D0) JET0097
PAI2=2.D0*Datan(1.D0) JET0098
DEG=180.D0/PAI JET0099
AR=8.3143D3 JET0100
AV=6.022D 26 JET0101
AW=7.27D0 JET0102
RH00=0.0075D0 JET0103
T0=2300.D0 JET0104
G=1.54D0 JET0105
D=2.5D-10 JET0106
MEXIT=4.D0 JET0107
MFIN=34.D0 JET0108
XC=0.5D0 JET0109
YC=2.5D0 JET0110
C DELTA=0 CORRESPONDS TO PLANE SYMMETRY JET0112
C DELTA=1 CORRESPONDS TO CYLINDRICAL SYMMETRY JET0113
DELTA=1.D0 JET0114
FRACG=0.6D0 JET0115
EPSIL=1.D-8 JET0116
ITER0=20 JET0117
KF0=101 JET0118
JMAX=1001 JET0119
STAB=0.50D0 JET0120
DDY=1.05D0 JET0121
DYMAX=0.5D0 JET0122
YMAX=50.D0 JET0123
DY0=YC/250.D0 JET0124
IDEI=1 JET0125
JDEL=1 JET0126
C POINTS FOR PRINTING FLOW FIELD AT YF=YXI(JXI) JET0127
JXI=1 JET0128
JYXI=11 JET0129
DYXI=5.D0 JET0130
YXI(1)=YC+0.5D0 JET0131
YXI(2)=YXI(1)+2.D0 JET0132
IO=2 JET0133
DO 1 I=IO,JYXI JET0134
YXI(I)=YXI(IO)+DYXI*DFLOAT(I-IO) JET0135
1 CONTINUE JET0136
IF(KF0.GT.101) CALL FIN(101) JET0137
IF(JMAX.GT.1001) CALL FIN(102) JET0138
IF(FRACG.GT.1.D0 .OR. FRACG.LT.0.) CALL FIN(103) JET0139
IF(JYXI.GT.20) CALL FIN(104) JET0140
IF(DELTA*(1.D0-DELTA).NE.0.) CALL FIN(105) JET0141
NO=RHO0*AV/AW JET0142
AO=DSQRT(G*AR*T0/AW) JET0143
PO=AR*RHO0*T0/AW JET0144

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SIGMA=PAI*D**2 JET0145
LAMDA0=1.D0/(DSQRT(2.D0)*SIGMA*N0) JET0146
G1=(G-1.D0)/2.D0 JET0147
G2=(G+1.D0)/(2.D0*(G-1.D0)) JET0148
G3=G/2.D0 JET0149
G4=(G+1.D0)/(G-1.D0) JET0150
G5=DSQRT((G+1.D0)/(G-1.D0)) JET0151
G6=1.D0/(G-1.D0) JET0152
G7=2.D0/(G+1.D0) JET0153
G8=(0.5D0*(G+1.D0)**2/(G-1.D0))**(1.D0/(G+1.D0))* JET0154
1 ((G+1.D0)/(G-1.D0))**((G-1.D0)/(G+1.D0)) JET0155
G9=(G+3.D0)/(2.D0*(G-1.D0)) JET0156
G10=(7.D0-3.D0*G)/(2.D0*(G-1.D0)) JET0157
G11=(2.D0/(G+1.D0))**(1.D0/(G-1.D0)) JET0158
G12=DSQRT((G+1.D0)/(G-1.D0))-1.D0 JET0159
G13=(2.D0-G)/(2.D0*(G-1.D0)) JET0160
G14=G/(2.D0*(G-1.D0)) JET0161
G15=(G+1.D0)/(3.D0-G) JET0162
G16=(G+1.D0)/4.D0 JET0163
G20=LAMDA0*DSQRT(PAI*G/8.D0) JET0164
ZETA1=G5*DATAN(DSQRT(MEXIT**2-1.D0)/G5) JET0165
AMU1=DARSIN(1.D0/MEXIT) JET0166
PSI1=PAI2+AMU1 JET0167
ZETAF=G5*DATAN(DSQRT(MFIN**2-1.D0)/G5) JET0168
PSIF=PSI1+ZETA1-ZETAF JET0169
NU0=0. JET0170
TETLIM=NUFUNC(MEXIT)+PAI2-NU0 JET0171
PSILIM=TETLIM JET0172
TETSYM=PAI-2.D0*TETLIM JET0173
GOREM=1.D0+G1*MEXIT**2 JET0174
RH01=RHO0/GOREM**G6 JET0175
V1=MEXIT*A0/DSQRT(GOREM) JET0176
P1=P0/GOREM***(G/(G-1.D0)) JET0177
T1=T0/DSQRT(GOREM) JET0178
YYC=2.D0*PAI*YC JET0179
IF(DELTA.EQ.0.) YYC=1.D0 JET0180
MDOT1=YYC*XC*RH01*V1 JET0181
C
21 PRINT 21,AR,AV,AW,G,RH00,N0,P0,T0,A0,D JET0182
  FORMAT(/1X,'THERMODYNAMIC DATA:',/
1      1X,'AR,AV,AW,G=',2X,2D14.5,2F9.3/ JET0183
2      1X,'RH00,N0,P0,T0,A0,D=',6D13.5) JET0184
22 PRINT 22,XC,YC,MEXIT,RH01,P1,T1,V1,MDOT1,PSI1*DEG,PSIF*DEG, PSILIM*DEG JET0185
  FORMAT(/1X,'CORNER DATA: XC,YC=',2F9.2/ JET0186
1      1X,'EXIT CONDITIONS:', JET0187
2      2X,'MEXIT,RH01,P1,T1,V1,MDOT1=',F9.3,5D13.4/ JET0188
3      1X,'CENTERED FAN LIMITS:', JET0189
4      2X,'PSI1,PSIF,PSILIM=',3F10.3) JET0190
23 PRINT 23,DELTA,KF0,JMAX,ITER0,DY0,YMAX,STAB,DDY JET0191
  FORMAT(/1X,'INTEGRATION DATA.   SYMMETRY INDEX: DELTA=',F4.1/,1X,'NUMBER OF POINTS IN X AND Y DIRECTIONS: KF0,JMAX=',2I5/ JET0192
1      1X,'MAX. NUM. OF ITERATIONS ITER0=',I5/ JET0193
5      1X,'INITIAL Y-STEP AND MAXIMUM Y: DY0,YMAX=',2D14.5/ JET0194
6      1X,'Y-STEP STABILITY FACTORS STAB,DDY=',2F7.3) JET0195
  RETURN JET0196
  END JET0197
          BEGIN JET0198
SUBROUTINE BEGIN JET0199
C SUBROUTINE NUMBER 2 JET0200
  IMPLICIT REAL*8(A-H,L-Z,$) JET0201
  COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), TETAF(101),BF(101), JET0202
1      TETAF(101),BN(101), XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET0203
2      BN(101),XTEMP(101) JET0204
3      TETAN(101),BN(101),XTEMP(101) JET0205
COMMON/THICKY/XTH(1002),TH(1002) JET0206
COMMON/GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15, G16,G17,G18,G19,G20 JET0207
COMMON/PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, TETS, TETLIM,DDY,DYMAX JET0208
2      TETS, TETLIM,DDY,DYMAX JET0209
COMMON/STAG/RHO0,N0,P0,T0,A0,MDOT1 JET0210

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COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,
1           KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD
COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
1           RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),
2           TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),
3           CSIGNN(92),CSIGNF(92),MCHARI(92),MCHARN(92),MCHARF(92),
4           MCHARI(92)
COMMON /ICHARA/KCHARP,KCHARM,KCHARO

C C DEFINE INITIAL CHARACTERISTIC PARAMETERS. USE INTERPOLATION OF
C RIEMANN INVARIANT ACROSS THE FAN.
      KCHARP=IDINT(FRACG*DFLOAT(KF0-1)+1.D-6)+1
      KCHAR0=KCHARP+1
      KCHARM=KCHAR0-KCHARP
      IF(KCHARP.LT.2) CALL FIN(200)
      IF(KCHAR0.GT.92) CALL FIN(210)
      IF(KCHARM.LT.1) CALL FIN(205)
      NU1=NUFUNC(MEXIT)
      RM1=NU0
      TET1=RM1-NU1
      RP0=NU1-TET1
      NUFIN=NUFUNC(MFIN)
      RPFIN=NUFIN-(RM1-NUFIN)
      DRP=(RPFIN-RP0)/DFLOAT(KCHARP-1)
      DO 1 KC=1,KCHARP
      RP1=RP0+DRP*DFLOAT(KC-1)
      CALL RFUNC(RM1,RP1,M1,MU1,TETA1)
      MCHARI(KC)=M1
      1 CONTINUE

C 1 DATA FOR C+ CHARACTERISTICS.
C THE RIEMANN INVARIANTS ARE DEFINED IN SUCH A WAY THAT BOTH VANISH AT
C INFINITE MACH NUMBER.
      RM1=NU0
      DO 2 KC=1,KCHARP
      CSIGNF(KC)=1.D0
      XCHARF(KC)=XC
      YCHARF(KC)=YC
      IF(MCHARI(KC).EQ.0.) CALL FIN(231)
      NU=NUFUNC(MCHARI(KC))
      TET=RM1-NU
      RP1=NU-TET
      CALL RFUNC(RM1,RP1,M1,MU1,TETA1)
      MCHARF(KC)=M1
      MUCARF(KC)=MU1
      TCHARF(KC)=TETA1
      RMCARF(KC)=RM1
      RPCARF(KC)=RP1
      2 CONTINUE

C 2 DATA FOR C- CHARACTERISTICS.
      KC1=KCHARP+1
      XCHARF(KC1)=0.8D0*XC
      DO 21 KC=KC1,KCHAR0
      CSIGNF(KC)=-1.D0
      MCHARI(KC)=MEXIT
      MUCARF(KC)=DARSIN(1.D0/MCHARI(KC))
      TCHARF(KC)=PAI2
      YCHARF(KC)=YC
      MCHARF(KC)=MEXIT
      RMCARF(KC)=RM1
      RPCARF(KC)=NUFUNC(MEXIT)-(TCHARF(KC)-TETLIM)
      21 CONTINUE

C 21 DEFINE GRID AND INITIAL CONDITIONS AT EXIT PLANE.
      KFAN=KCHARP-1
      ILEAD=KF0-KFAN
      KCLEAD=1
      KF=KF0
      KF2=2*KF
      YF=YC
      DO 3 I=1,KF
      KC=KCLEAD+I-ILEAD
      IF(KC.GT.KCHARP) CALL FIN(241)

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IF(KC.GE.1) GO TO 31 JET0289
XF(I)=DFLOAT(I-1)*XC/DFLOAT(ILEAD-1) JET0290
MF(I)=MEXIT JET0291
TETA(I)=PAI2 JET0292
GO TO 32 JET0293
31 CONTINUE JET0294
XF(I)=XC JET0295
MF(I)=MCHARF(KC) JET0296
TETA(I)=TCHARF(KC) JET0297
32 CONTINUE JET0298
RMF(I)=NUFUNC(MF(I))+(TETA(I)-TELIM) JET0299
RPF(I)=NUFUNC(MF(I))-(TETA(I)-TELIM) JET0300
MUF(I)=DARSIN(1.D0/MF(I)) JET0301
BF(I)=0. JET0302
3 CONTINUE JET0303
DY=DYO JET0304
DO 4 KC=1,KCHARO JET0305
CSIGNN(KC)=CSIGNF(KC) JET0306
4 CONTINUE JET0307
DO 5 I=1,KN JET0308
BN(I)=0. JET0309
5 CONTINUE JET0310
RETURN JET0311
END JET0312
SUBROUTINE PRINT JET0313
C SUBROUTINE NUMBER 3 JET0314
IMPLICIT REAL*8(A-H,L-Z,$) JET0315
REAL*4 XPL,YPL JET0316
COMMON /PLUME/XPL(1002,10),YPL(1002) JET0317
COMMON /IPLUME/KPL,ITYPL(10) JET0318
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0319
1 TETA(I),BF(I), JET0320
2 XC(101),RMN(101),RPN(101),MN(101),MUN(101), JET0321
3 TETAN(101),BN(101),XTEMP(101) JET0322
COMMON/THICKY/XTH(1002),TH(1002) JET0323
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF JET0324
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET0325
1 ,XIAPP(101,20),XIF(101,20) JET0326
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0327
1 G16,G17,G18,G19,G20 JET0328
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT, JET0329
1 STAB,DELTA,PSII,PSIF,ZETA1,SIGMA,FRAVG,EPSIL,NU0, JET0330
2 TETSYM,TETLIM,DDY,DYMAX JET0331
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1 JET0332
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET0333
1 RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92), JET0334
2 TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92), JET0335
3 CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92), JET0336
4 MCHARI(92) JET0337
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET0338
1 KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET0339
COMMON /ROW/YF,YN,DXF,DXN JET0340
C SUM=0. JET0341
KF1=KF-1 JET0342
DO 10 I=1,KF1 JET0343
DX=XF(I+1)-XF(I) JET0344
GOREM=1.D0+G1*MF(I)**2 JET0345
GOREM1=1.D0+G1*MF(I+1)**2 JET0346
RATTEM=RH00*A0*MF(I )*DSINK(TETA(I ))/GOREM **(G6+0.5D0) JET0347
RATEP=RH00*A0*MF(I+1)*DSINK(TETA(I+1))/GOREM1***(G6+0.5D0) JET0348
SUM=SUM+DX*(RATTEM+RATEP)/2.D0 JET0349
10 CONTINUE JET0350
YYF=2.D0*PAI*YF JET0351
IF(DELTA.EQ.0.) YYF=1.D0 JET0352
MDOTFR=YYF*SUM/MDOT1 JET0353
PRINT 11, J,KCLEAD,KF,ILEAD,YF,DY,XF(KF),MF(KF),MDOTFR JET0354
11 FORMAT(1X,'J,KCLEAD,KF,ILEAD,YF,DY,XF(KF),MF(KF),MDOTFR=', JET0355
1 415,5D12.4) JET0356
C PRINT FLOW FIELD AT Y=YF JET0357
C JET0358
C JET0359
C JET0360

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PRINT

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IF(J.EQ.JMAX) JXI=MINO(JXI,JYXI) JET0361
IF(J.EQ.1 .OR. J.EQ.JMAX) GO TO 121 JET0362
IF(JXI.GT.JYXI) GO TO 120 JET0363
IF(YXI(JXI).GT.YF+0.5D0*DY) GO TO 120 JET0364
121 CONTINUE JET0365
YXI(JXI)=YF JET0366
CALL OPACX JET0367
C COMPUTE MACH NUMBER FOR CYLINDRICAL EXPANSION MCYL. JET0368
F=(YF/YC)*(G7*(1.D0+G1*MEXIT**2))**G2/MEXIT JET0369
CALL AREAF(F,MCYL) JET0370
PRINT 22,JXI,KCLEAD,ILEAD,KF,MCYL,YF JET0371
22 FORMAT(1X,'PRINTING NUMBER JXI,KCLEAD,ILEAD,KF=',4I4, JET0372
1      5X,'MCYL,YF=',2D14.5/) JET0373
1 PRINT 1 JET0374
1 FORMAT(1X,' I ',' KC ',' XF(I) ',' TETAFC(I) ', JET0375
1           MF(I) ',' MAB ', JET0376
2           MABI ',' MOBI ', JET0377
3           XI(I) ',' XIGRP(I) ', JET0378
4           XIAPP(I) ',' XIPM(I) ') JET0379
1 IDELL=IDEL JET0380
IF(J.EQ.1.OR.J.EQ.JMAX) IDELL=1 JET0381
DO 20 I=1,KF,IDEALL JET0382
KC=KCLEAD+(I-ILEAD) JET0383
IF(KC.LT.KCLEAD) KC=0 JET0384
MOB=1.D10 JET0385
MOBI=1.D10 JET0386
MAB=1.D10 JET0387
MABI=1.D10 JET0388
MPM=MF(I) JET0389
IF(KC.EQ.0) GO TO 23 JET0390
MOB=MCHARI(KC) JET0391
IF(J.EQ.1) GO TO 23 JET0392
PSIPM=PAI2-DATAN((XF(I)-XC)/(YF-YC)) JET0393
ZETA=PSI1+ZETA1-PSIPM JET0394
MPM=DSQRT((G5*DTAN(ZETA/G5))**2+1.D0) JET0395
CALL MATCH(I,MOB,MAB,MOBI,MABI) JET0396
23 CONTINUE JET0397
PRINT 21,I,KC,XF(I),TETAFC(I)*DEG,MF(I),MAB,MABI,MOBI, JET0398
1           XI(I,JXI),XIGRP(I,JXI),XIAPP(I,JXI),XIPM(I,JXI) JET0399
21 FORMAT(1X,2I4,10D12.4) JET0400
20 CONTINUE JET0401
IF(J.EQ.1) GO TO 120 JET0402
IF(J.EQ.JMAX) GO TO 120 JET0403
JXI=JXI+1 JET0404
120 CONTINUE JET0405
IF(J.LT.JMAX) GO TO 200 JET0406
PRINT 101 JET0407
101 FORMAT('1') JET0408
PRINT 102 JET0409
102 FORMAT(1X,'RADIAL MOLECULAR THICKNESS J,XTH(J),TH(J)='/) JET0410
PRINT 202,(JJ,XTH(JJ),TH(JJ),JJ=1,JMAX) JET0411
202 FORMAT(/5(I5,D11.4,D10.3)) JET0412
PRINT 101 JET0413
PRINT 103,(IPL,ITYPL(IPL),IPL=1,KPL) JET0414
103 FORMAT(1X,'PLUME TYPES IPL,ITYPL(IPL)=' , JET0415
1           2(/1X,5(5X,2I4))) JET0416
PRINT 104 JET0417
104 FORMAT(1X,'PLUME POINTS J,YPL(J),XPL(J,1),XPL(J,2),...='/) JET0418
JDELL=1 JET0419
DO 203 JJ=1,JMAX,JDELL JET0420
PRINT 204,JJ,YPL(JJ),(XPL(JJ,IPL),IPL=1,KPL) JET0421
204 FORMAT(1X,I5,2X,E12.4,10E11.3) JET0422
203 CONTINUE JET0423
C WRITE ON TAPE7 FOR SUBSEQUENT PLOTTING. JET0424
C NO MORE THAN 80 CHARACTERS PER LINE ON TAPE7. JET0425
WRITE(7,205) JMAX,KPL JET0426
205 FORMAT(8I10/8I10) JET0427
WRITE(7,205) (ITYPL(IPL),IPL=1,KPL) JET0428
DO 210 JJ=1,JMAX JET0429
WRITE(7,211) YPL(JJ),(XPL(JJ,IPL),IPL=1,KPL) JET0430
211 FORMAT(6E13.6/2X,6E13.6/2X,6E13.6/2X,6E13.6) JET0431
210 CONTINUE JET0432

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C WRITE LATERAL (X) OPACITIES          JET0433
  JXI0=JXI                           JET0434
  WRITE(7,205) JXI0,KF0               JET0435
  PRINT 226, JXI0,KF0               JET0436
226  FORMAT(//1X,'LATERAL (X) OPACITIES JXI0,KF0=',2I8) JET0437
    DO 220 JXI=1,JXI0                JET0438
    WRITE(7,221) JXI,YXI(JXI)        JET0439
221  FORMAT(I10,E13.6)              JET0440
    PRINT 227, JXI,YXI(JXI)        JET0441
227  FORMAT(//1X,'JXI,YXI(JXI)=',I8,E15.6/) JET0442
    DO 225 I=1,KF0                JET0443
    WRITE(7,211) XIF(I,JXI),XI(I,JXI),XIPM(I,JXI),XIGRP(I,JXI),
1      XIAPP(I,JXI)                JET0444
    PRINT 211, XIF(I,JXI),XI(I,JXI),XIPM(I,JXI),XIGRP(I,JXI),
1      XIAPP(I,JXI)                JET0445
225  CONTINUE                      JET0446
220  CONTINUE                      JET0447
200  CONTINUE                      JET0448
    RETURN                         JET0449
    END                           JET0450
                                         FIN
C SUBROUTINE FIN(IFIN)                JET0453
C SUBROUTINE NUMBER 4                 JET0454
C STOP WHEN ERROR IS DETECTED.       JET0455
  IMPLICIT REAL*8(A-H,L-Z,$)        JET0456
  PRINT 1,IFIN                      JET0457
1   FORMAT(1X,'FIN CODE IFIN=',I6/)  JET0458
C INDUCE ERROR IN ORDER TO GENERATE TRACING OF CALLING SUBROUTINES. JET0459
  X=-1.0D0                          JET0460
  Y=X+DSQRT(X)                     JET0461
  IF(IFIN.LE.0) GO TO 100           JET0462
  STOP                            JET0463
100  RETURN                         JET0464
  END                           JET0465
                                         MARCH
C SUBROUTINE MARCH                  JET0466
C SUBROUTINE NUMBER 5                 JET0467
  IMPLICIT REAL*8(A-H,L-Z,$)        JET0468
  COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
1    TETAF(101),BF(101),             JET0469
2    XN(101),RMN(101),RPN(101),MN(101),MUN(101),             JET0470
3    TETAN(101),BN(101),XTEMP(101) JET0471
  COMMON /THICKY/XTH(1002),TH(1002) JET0472
  COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15, JET0473
1    G16,G17,G18,G19,G20             JET0474
  COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0475
1    STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSSIL,NU0,           JET0476
2    TETSYM,TETLIM,DDY,DYMAX         JET0477
  COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1 JET0478
  COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,                   JET0479
1    KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD             JET0480
  COMMON /ROW/YF,YN,DXF,DXN          JET0481
  COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET0482
1    RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),             JET0483
2    TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),             JET0484
3    CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),             JET0485
4    MCHARI(92)                      JET0486
  COMMON /ICHARA/KCHARP,KCHARM,KCHARO JET0487
C ADVANCE FLOW FIELD FROM YF TO YN JET0488
  IM=KF                           JET0489
  IP=KF                           JET0490
  YN=YF+DY                         JET0491
  KN=KF0                          JET0492
C SEMI-INVERSE INTEGRATION FOR FAN POINTS. JET0493
  CALL SEMINV                      JET0494
C NEW GRID POINTS (JUST INVERSE MARCHING). JET0495
  CALL GRIDN                      JET0496
C LOAD FLOW VARIABLES FROM SEMI-INVERSE INTEGRATION INTO VECTORS JET0497
  CALL LOADC                      JET0498
C CHARACTERISTIC SCHEME INTEGRATION FOR INNER POINTS (INVERSE MARCH). JET0499
  CALL INVMAR                      JET0500
  RETURN                         JET0501
  END                           JET0502
                                         
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SUBROUTINE INVMAR                                         JET0505
C SUBROUTINE NUMBER 6                                     JET0506
IMPLICIT REAL*8(A-H,L-Z,$)                               JET0507
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
1          TETA(101),BFC(101),                                JET0509
2          XN(101),RMN(101),RPN(101),MN(101),MUN(101),      JET0510
3          TETAN(101),BN(101),XTEMP(101)                      JET0511
COMMON /THICKY/XTH(1002),TH(1002)                      JET0512
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0513
1          G16,G17,G18,G19,G20                                 JET0514
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,JET0515
1          STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NUO,JET0516
2          TETSYM,TETLIM,DDY,DYMAX                         JET0517
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1                   JET0518
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,           JET0519
1          KF2,IDE1,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD       JET0520
COMMON /ROW/YF,YN,DXF,DXN                             JET0521
C
C INTEGRATION WITH INVERSE CHARACTERISTICS FOR NEW POINT(X4,Y4). JET0522
C OLD POINTS ARE (X1,Y1),(X2,Y2).                           JET0524
C X1 IS OBTAINED BY INVERSE C- FROM X4                     JET0525
C X2 IS OBTAINED BY INVERSE C+ FROM X4                     JET0526
C NOTE THAT X1 MAY BE NEGATIVE (E. G. WHEN X4=0).          JET0527
KN1=ILEAD-1                                              JET0528
IF(KN1.LE.0) CALL FIN(601)                               JET0529
DO 1000 I=1,KN1                                         JET0530
I4=I                                                       JET0531
X4=XN(I)                                                 JET0532
Y4=YN                                                       JET0533
IF4=(IM+IP)/2                                           JET0534
CALL INTERP(0,IF4,KF,X4,XF,RM4,RMF,RP4,RPF)           JET0535
CALL RFUNC(RM4,RP4,M4,MU4,TETA4)                       JET0536
M14=M4                                                   JET0537
MU14=MU4                                                 JET0538
TETA14=TETA4                                            JET0539
M24=M4                                                   JET0540
MU24=MU4                                                 JET0541
TETA24=TETA4                                            JET0542
Y1=YF                                                     JET0543
Y2=YF                                                     JET0544
Y14=(Y1+Y4)/2.D0                                         JET0545
Y24=(Y2+Y4)/2.D0                                         JET0546
X1=1.D10                                                 JET0547
X2=1.D10                                                 JET0548
RM4=1.D10                                                JET0549
RP4=1.D10                                                JET0550
ITER=0                                                    JET0551
GO TO 2                                                   JET0552
C
C CORRECTOR                                              JET0553
C
1  ITER=ITER+1                                           JET0554
C AVERAGED PROPERTIES ON C-(14),C+(24) CHARACTERISTICS. JET0555
RM14=(RM1+RM4)/2.D0                                      JET0556
RP14=(RP1+RP4)/2.D0                                      JET0558
RM24=(RM2+RM4)/2.D0                                      JET0559
RP24=(RP2+RP4)/2.D0                                      JET0560
C M14,MU14,TETA14, M24,MU24,TETA24 AVERAGED ON C-,C+ CHARACTERISTICS. JET0561
CALL RFUNC(RM14,RP14,M14,MU14,TETA14)                   JET0562
CALL RFUNC(RM24,RP24,M24,MU24,TETA24)                   JET0563
2  CONTINUE                                               JET0564
C NEW X1,X2                                              JET0565
X10=X1                                                    JET0566
X20=X2                                                    JET0567
X1=X4-DY/DTAN(TETA14-MU14)                            JET0568
X2=X4-DY/DTAN(TETA24+MU24)                            JET0569
IF(X2.LT.0.) CALL FIN(670)                            JET0570
D14=DSQRT((X1-X4)**2+DY**2)                          JET0571
D24=DSQRT((X2-X4)**2+DY**2)                          JET0572
C INTERPOLATE OLD DISTRIBUTION FOR RM1,RP1, RM2,RP2 AT X1,X2. JET0573
CALL INTERP(0,IM,KF,X1,XF,RM1,RMF,RP1,RPF)           JET0574
CALL INTERP(0,IP,KF,X2,XF,RM2,RMF,RP2,RPF)           JET0575

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C NO NEED FOR RE-AVERAGING SINCE IT INTRODUCES ONLY HIGHER ORDER JET0577
C CHANGES INTO THE ITERATION SCHEME. JET0578
C INTEGRATE THE CHARACTERISTIC EQUATIONS FOR RM4,RP4 AT X4,Y4. JET0579
  RM40=RM4
  RP40=RP4
  RM4=RM1+DELTA*DSIN(TETA14)*D14/(M14*Y14)
  RP4=RP2+DELTA*DSIN(TETA24)*D24/(M24*Y24)
C CONVERGENCE TEST JET0580
  EPS=(DABS(X1-X10)+DABS(X2-X20))/DY+DABS(RM4-RM40)+DABS(RP4-RP40) JET0581
  IF(ITER.GT.ITER0) GO TO 10 JET0582
  IF(EPS.GT.EPSIL) GO TO 1 JET0583
  RMN(I)=RM4 JET0584
  RPN(I)=RP4 JET0585
  CALL RFUNC(RM4,RP4,MN(I),MUN(I),TETAN(I)) JET0586
1000 CONTINUE JET0587
  RETURN JET0588
10 CONTINUE JET0589
  PRINT 11,I4,KN,IF4,IM,IP,KF,ITER,ITER0,EPS,EPSIL,X1,X2,X4,M14,M24 JET0590
11 FORMAT(1X,'SUBR. INVMAR. I4,KN,IF4,IM,IP,KF,ITER,ITER0=',8I5/ JET0591
   1      1X,'EPS,EPSIL,X1,X2,X4,M14,M24=',7D14.6/) JET0592
  CALL FIN(611) JET0593
  RETURN JET0594
END SEMINV JET0595
SUBROUTINE SEMINV JET0596
C SUBROUTINE NUMBER 7 JET0597
  IMPLICIT REAL*8(A-H,L-Z,$) JET0598
  COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0599
   1      TETAF(101),BF(101), JET0600
   2      XN(101),RMNC(101),RPN(101),MN(101),MUN(101), JET0601
   3      TETAN(101),BN(101),XTEMP(101) JET0602
  COMMON/THICKY/XTH(1002),TH(1002) JET0603
  COMMON/GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0604
   1      G16,G17,G18,G19,G20 JET0605
  COMMON/PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0606
   1      STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET0607
   2      TETSYM,TETLIM,DDY,DYMAX JET0608
  COMMON/STAG/RH00,NO,PO,TO,A0,MDOT1 JET0609
  COMMON/IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET0610
   1      KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET0611
  COMMON/ROW/YF,YN,DXF,DZN JET0612
  COMMON/CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET0613
   1      RMCARF(92),RPCARF(92),RMCAFN(92),RPCARN(92), JET0614
   2      TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92), JET0615
   3      CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92), JET0616
   4      MCHARI(92) JET0617
  COMMON/ICHARA/KCHARP,KCHARM,KCHARO JET0618
C COMPUTE NEW POINT (X4,Y4), BY PASSING A C+ CHARACTERISTIC JET0619
C THROUGH OLD POINT (X2,Y2). BOTH POINTS ARE ON CHARACTERISTIC LINE JET0620
C NUMBER KC. JET0621
  IM=1 JET0622
  DO 100 KC=1,KCHAR0 JET0623
  IF(CSIGNN(KC).EQ.0.) GO TO 100 JET0624
C PREDICTOR JET0625
C
  Y1=YF JET0626
  Y2=YF JET0627
  Y4=YN JET0628
  Y14=(Y1+Y4)/2.D0 JET0629
  Y24=(Y2+Y4)/2.D0 JET0630
  X2=XCHARF(KC) JET0631
  RM2=RMCARF(KC) JET0632
  RP2=RPCARF(KC) JET0633
  M2=MCHARF(KC) JET0634
  MU2=MUCARF(KC) JET0635
  TETA2=TCHARF(KC) JET0636
  M14=M2 JET0637
  MU14=MU2 JET0638
  TETA14=TETA2 JET0639
  M24=M2 JET0640
  MU24=MU2 JET0641

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TETA24=TETA2          JET0649
X4=1.D10             JET0650
X1=1.D10             JET0651
RM4=1.D10             JET0652
RP4=1.D10             JET0653
ITER=0               JET0654
GO TO 2              JET0655
C                   JET0656
C   CORRECTOR         JET0657
C
1      ITER=ITER+1    JET0659
C   AVERAGED PROPERTIES ON C-(14),C+(24) CHARACTERISTICS. JET0660
  RM14=(RM1+RM4)/2.D0 JET0661
  RP14=(RP1+RP4)/2.D0 JET0662
  RM24=(RM2+RM4)/2.D0 JET0663
  RP24=(RP2+RP4)/2.D0 JET0664
C   M14,MU14,TETA14, M24,MU24,TETA24 AVERAGED ON C-,C+ CHARACTERISTICS. JET0665
  CALL RFUNC(RM14,RP14,M14,MU14,TETA14) JET0666
  CALL RFUNC(RM24,RP24,M24,MU24,TETA24) JET0667
2      CONTINUE        JET0668
C   NEW X4,X1          JET0669
  X40=X4              JET0670
  X10=X1              JET0671
  X4=X2+DY/DTAN(TETA24+CSIGNF(KC)*MU24) JET0672
  X1=X4-DY/DTAN(TETA14-CSIGNF(KC)*MU14) JET0673
  D14=DSQRT((X1-X4)**2+DY**2)           JET0674
  D24=DSQRT((X2-X4)**2+DY**2)           JET0675
C   INTERPOLATE OLD DISTRIBUTION FOR RM1,RP1, AT X1. JET0676
  CALL INTERP(0,IM,KF,X1,XF,RM1,RMF,RP1,RPF) JET0677
  IF(J.GT.1) GO TO 22 JET0678
  IF(CSIGNF(KC).LT.0.) GO TO 22 JET0679
  RP1=RP2              JET0680
22     CONTINUE        JET0681
C   NO NEED FOR RE-AVERAGING SINCE IT INTRODUCES ONLY HIGHER ORDER JET0682
C   CHANGES INTO THE ITERATION SCHEME. JET0683
C   INTEGRATE THE CHARACTERISTIC EQUATIONS FOR RM4,RP4 AT X4,Y4. JET0684
  RM40=RM4              JET0685
  RP40=RP4              JET0686
  IF(CSIGNF(KC).LT.0.) GO TO 21 JET0687
  RM4=RM1+DELTA*DSIN(TETA14)*D14/(M14*Y14) JET0688
  RP4=RP2+DELTA*DSIN(TETA24)*D24/(M24*Y24) JET0689
  GO TO 20              JET0690
21     CONTINUE        JET0691
  RM4=RM2+DELTA*DSIN(TETA24)*D24/(M24*Y24) JET0692
  RP4=RP1+DELTA*DSIN(TETA14)*D14/(M14*Y14) JET0693
20     CONTINUE        JET0694
C   CONVERGENCE TEST   JET0695
  EPS=(DABS(X4-X40)+DABS(X1-X10))/DY+DABS(RM4-RM40)+DABS(RP4-RP40) JET0696
  IF(ITER.GT.ITER0) GO TO 10 JET0697
  IF(EPS.GT.EPSIL) GO TO 1 JET0698
  CSIGNN(KC)=CSIGNF(KC) JET0699
  IF(X4.GT.0.) GO TO 30 JET0700
  RMSAVE=RM4              JET0701
  RM4=RP4+TETSYM          JET0702
  RP4=RM4-TETSYM          JET0703
  CSIGNN(KC)=-1.D0         JET0704
30     CONTINUE        JET0705
  RMCARN(KC)=RM4            JET0706
  RPCARN(KC)=RP4            JET0707
  CALL RFUNC(RM4,RP4,M4,MU4,TETA4) JET0708
  TCHARN(KC)=TETA4          JET0709
  XCHARN(KC)=DABS(X4)       JET0710
  YCHARN(KC)=Y4              JET0711
  MUCARN(KC)=MU4            JET0712
  MCHARN(KC)=M4              JET0713
100    CONTINUE        JET0714
  RETURN                JET0715
10     CONTINUE        JET0716
  PRINT 11,KC,KCHAR0,IM,KF,ITER,ITER0,EPS,EPSIL,X1,X2,X4,M14,M24 JET0717
11     FORMAT(1X,'SUBR. SEMINV. KC,KCHAR0,IM,KF,ITER,ITER0=',6I5/ JET0718
1           1X,'EPS,EPSIL,X1,X2,X4,M14,M24=',7D14.6/) JET0719
  CALL FIN(711)           JET0720

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RETURN END	RFUNC	JET0721 JET0722	
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SUBROUTINE RFUNC(RM,RP,M,MU,TETA)			
IMPLICIT REAL*8(A-H,L-Z,\$)			
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),			
1	TETAF(101),BF(101),	JET0723	
2	XN(101),RMN(101),RPN(101),MN(101),MUN(101),	JET0724	
3	TETAN(101),BN(101),XTEMP(101)	JET0725	
COMMON/THICKY/XTH(1002),TH(1002)			
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0731			
1	G16,G17,G18,G19,G20	JET0726	
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,			
1	STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,	JET0727	
2	TETSYM,TETLIM,DDY,DYMAX	JET0728	
COMMON /STAG/RH00,NO,PO,TO,A0,MDOT1			
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,			
1	KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD	JET0729	
COMMON /ROW/YF,YN,DXF,DXN			JET0730
C COMPUTE M,MU,TETA AT A POINT, AS FUNCTION OF RIEMANN INVAR. RM,RP.			JET0731
TETA=(RM-RP)/2.D0+TETLIM			JET0732
NU =(RM+RP)/2.D0			JET0733
C NU=NU0-(G5*ARCTAN(G5*Q)-ARCTAN(Q)), WHERE Q=(M**2-1)**(-1/2)			JET0734
C FIND Q(NU), AND HENCE M(NU), THROUGH NEWTON RAPHSON ITERATIONS.			JET0735
Q=-(NU-NU0)/(G4-1.D0)			JET0736
IF(Q.LE.0.) CALL FIN(801)			JET0737
1	ITER=0	JET0738	
1	ITER=ITER+1	JET0739	
QF=Q			JET0740
DNUDT=-(G4-1.D0)/((1.D0+G4*Q**2)*(1.D0+Q**2))			JET0741
DNU=NU-(NU0-(G5*DATAN(G5*Q)-DATAN(Q)))			JET0742
Q=Q+DNU/DNUDT			JET0743
IF(Q.LE.0.) CALL FIN(811)			JET0744
EPS=DABS(Q-QF)/Q			JET0745
IF(ITER.GT.ITER0) GO TO 10			JET0746
IF(EPS.GT.EPSIL*1.D-3) GO TO 1			JET0747
M=DSQRT(1.D0+1.D0/Q**2)			JET0748
MU=DARSIN(1.D0/M)			JET0749
RETURN			JET0750
10	CONTINUE	JET0751	
CALL FIN(810)			JET0752
RETURN			JET0753
END			JET0754
SUBROUTINE INTERP(JNEW,I,KGRID,X,XVEC,RM,RMVEC,RP,RPVEC)			INTERP
C SUBROUTINE NUMBER 9			JET0755
IMPLICIT REAL*8(A-H,L-Z,\$)			JET0756
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),			JET0757
1	TETAF(101),BF(101),	JET0758	
2	XN(101),RMN(101),RPN(101),MN(101),MUN(101),	JET0759	
3	TETAN(101),BN(101),XTEMP(101)	JET0760	
COMMON/THICKY/XTH(1002),TH(1002)			JET0761
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0762			JET0762
1	G16,G17,G18,G19,G20	JET0763	
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,			JET0764
1	STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,	JET0765	
2	TETSYM,TETLIM,DDY,DYMAX	JET0766	
COMMON /STAG/RH00,NO,PO,TO,A0,MDOT1			JET0767
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,			JET0768
1	KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD	JET0769	
COMMON /ROW/YF,YN,DXF,DXN			JET0770
DIMENSION XVEC(1),RMVEC(1),RPVEC(1)			JET0771
C FIND I SUCH THAT XVEC(I).LE.X.AND.XVEC(I+1).GE.X			JET0772
C FIND RM,RP BY LINEAR INTERPOLATION.			JET0773
C NOTE THAT X MAY BE NEGATIVE.			JET0774
IF(DABS(X).LE.XVEC(KGRID)) GO TO 901			JET0775
PRINT 900,X,KGRID,XVEC(KGRID)			JET0776
FORMAT(/1X,D15.7,I10,4X,D15.7/)			JET0777
CALL FIN(900)			JET0778
901	CONTINUE	JET0779	
KG2=2*KGRID			JET0780
			JET0781
			JET0782
			JET0783
			JET0784
			JET0785
			JET0786
			JET0787
			JET0788
			JET0789
			JET0790
			JET0791
			JET0792

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I0=MIN0(I,KGRID-2) JET0793
ICOUNT=0 JET0794
1 I=I0 JET0795
SIGN1=1.D0 JET0796
IF(I.GE.1) GO TO 10 JET0797
SIGN1=-1.D0 JET0798
I=I+2 JET0799
10 CONTINUE JET0800
IF(I.GT.KGRID) CALL FIN(901) JET0801
XX1=SIGN1*XVEC(I) JET0802
I1=I JET0803
IF(XX1.LE.X) GO TO 11 JET0804
I0=I0-1 JET0805
ICOUNT=ICOUNT+1 JET0806
IF(ICOUNT.GT.KG2) CALL FIN(911) JET0807
GO TO 1 JET0808
11 CONTINUE JET0809
I=I0+1 JET0810
SIGN2=1.D0 JET0811
IF(I.GE.1) GO TO 12 JET0812
SIGN2=-1.D0 JET0813
I=-I+2 JET0814
12 CONTINUE JET0815
IF(I.GT.KGRID) CALL FIN(912) JET0816
XX2=SIGN2*XVEC(I) JET0817
I2=I JET0818
IF(XX2.GE.X) GO TO 13 JET0819
I0=I0+1 JET0820
ICOUNT=ICOUNT+1 JET0821
IF(ICOUNT.GT.KG2) CALL FIN(913) JET0822
GO TO 1 JET0823
13 CONTINUE JET0824
F1=(XX2-X)/(XX2-XX1) JET0825
F2=1.D0-F1 JET0826
IF(F1.LT.0.) CALL FIN(991) JET0827
IF(F2.LT.0.) CALL FIN(992) JET0828
RM1=RMF(I1) JET0829
RP1=RPF(I1) JET0830
RM2=RMF(I2) JET0831
RP2=RPF(I2) JET0832
IF(SIGN1.LT.0.) RM1=RPF(I1)+TETSYM JET0833
IF(SIGN1.LT.0.) RP1=RMF(I1)-TETSYM JET0834
IF(SIGN2.LT.0.) RM2=RPF(I2)+TETSYM JET0835
IF(SIGN2.LT.0.) RP2=RMF(I2)-TETSYM JET0836
RM=F1*RM1+F2*RM2 JET0837
RP=F1*RP1+F2*RP2 JET0838
RETURN JET0839
END JET0840
INTERX JET0841


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C SUBROUTINE INTERX(JNEW,II,VARU,VAR,KGRID,X0,XVEC) JET0842
C SUBROUTINE NUMBER 10 JET0843
IMPLICIT REAL*8(A-H,L-Z,$) JET0843
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0844
1 TETAF(101),BF(101), JET0845
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET0846
3 TETAN(101),BN(101),XTEMP(101) JET0847
COMMON/THICKY/XTH(1002),TH(1002) JET0848
COMMON/GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0849
1 G16,G17,G18,G19,G20 JET0850
COMMON/PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0851
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET0852
2 TETSYM,TETLIM,DDY,DYMAX JET0853
COMMON/STAG/RHO0,NO,PO,TO,A0,MDOT1 JET0854
COMMON/IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET0855
1 KF2,IDEJ,JDDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET0856
COMMON/ROW/YF,YN,DXF,DZN JET0857
DIMENSION VAR(1),XVEC(1) JET0858
C FIND X0 AND II SUCH THAT XVEC(II)<X0<XVEC(II+1), AND X0 CORRESPONDS JET0859
C TO THE LOCATION AT WHICH VAR0 IS A LINEAR INTERPOLATION OF VAR(I). JET0860
X0=1.D23 JET0861
IFIRST=I1 JET0862
IF(II.GT.0) GO TO 10 JET0863
IFIRST=KGRID-IABS(II)+2 JET0864

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10 CONTINUE JET0865
DO 1 II=IFIRST,KGRID JET0866
I=II JET0867
IF(II.GT.0) GO TO 11 JET0868
I=KGRID-II+2 JET0869
11 CONTINUE JET0870
IF(I.LE.0) CALL FIN(1001) JET0871
IF(I.GT.KGRID) CALL FIN(1002) JET0872
IF(I.EQ.1) GO TO 1 JET0873
IF((VAR(I)-VAR0)*(VAR(I-1)-VAR0).GT.0.) GO TO 1 JET0874
IF(VAR(I).EQ.VAR(I-1)) GO TO 1 JET0875
F1=(VAR(I)-VAR0)/(VAR(I)-VAR(I-1)) JET0876
F2=1.D0-F1 JET0877
IF(F1.LT.0.) CALL FIN(1011) JET0878
IF(F2.LT.0.) CALL FIN(1012) JET0879
X0=F1*XVEC(I-1)+F2*XVEC(I) JET0880
I1=I-1 JET0881
GO TO 2 JET0882
1 CONTINUE JET0883
2 CONTINUE JET0884
RETURN JET0885
END JET0886

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BREAK

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SUBROUTINE BREAK JET0887
C SUBROUTINE NUMBER 11 JET0888
IMPLICIT REAL*8(A-H,L-Z,$) JET0889
REAL MB,MX,MY JET0890
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0891
1 TETAF(101),BF(101), JET0892
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET0893
3 TETAN(101),BN(101),XTEMP(101) JET0894
COMMON/THICKY/XTH(1002),TH(1002) JET0895
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0896
1 G16,G17,G18,G19,G20 JET0897
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0898
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET0899
2 TETSYM,TETLIM,DDY,DYMAX JET0900
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1 JET0901
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET0902
1 KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET0903
COMMON /ROW/YF,YN,DXF,DXN JET0904
C COMPUTE THE BREAKDOWN PARAMETER AT (I-1/2,K-1/2). STORE IN BN(I). JET0905
C COMPUTE THE BREAKDOWN PARAMETER AT (I-1/2,K-1/2). STORE IN BN(I). JET0906
YB=0.5D0*(YF+YN) JET0907
DYY=DY JET0908
IM=2 JET0909
DO 1 I=2,KN JET0910
X1=XN(I-1) JET0911
X2=XN(I) JET0912
DXX=X2-X1 JET0913
IF(X2.GT.XF(KF)) GO TO 2 JET0914
CALL INTERP(0,IM,KF,X1,XF,RM1,RMF,RP1,RPF) JET0915
CALL INTERP(0,IM,KF,X2,XF,RM2,RMF,RP2,RPF) JET0916
CALL RFUNC(RM1,RP1,M1,MU1,TETA1) JET0917
CALL RFUNC(RM2,RP2,M2,MU2,TETA2) JET0918
MX=0.5D0*((MN(I)-MN(I-1))+(M2-M1))/DXX JET0919
MY=0.5D0*((MN(I)-M2)+(MN(I-1)-M1))/DYY JET0920
MB=0.25D0*(MN(I-1)+MN(I)+M1+M2) JET0921
TETAB=0.25D0*(TETAN(I-1)+TETAN(I)+TETA1+TETA2) JET0922
GOREM=MB**2*(1.D0+G1*MB**2)**(G6-1.D0) JET0923
GRAD=MX*DCOS(TETAB)+MY*DSIN(TETAB) JET0924
B=G20*GOREM*GRAD JET0925
GO TO 3 JET0926
2 B=1.D22 JET0927
3 BN(I)=B JET0928
1 CONTINUE JET0929
BN(1)=BN(2) JET0930
RETURN JET0931
END JET0932

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OPACY

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SUBROUTINE OPACY JET0933
C SUBROUTINE NUMBER 12 JET0934
IMPLICIT REAL*8(A-H,L-Z,$) JET0935
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0936

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1           TETAF(101),BF(101),                           JET0937
2           XN(101),RMN(101),RPN(101),MN(101),MUN(101),   JET0938
3           TETAN(101),BN(101),XTEMP(101)                 JET0939
COMMON/THICKY/XTH(1002),TH(1002)                      JET0940
1           G16,G17,G18,G19,G20                         JET0942
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0943
1           STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,   JET0944
2           TETSYM,TETLIM,DDY,DYMAX                     JET0945
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1                  JET0946
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,          JET0947
1           KF2,IDELEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD    JET0948
COMMON /ROW/YF,YN,DXF,DXN                           JET0949
C COMPUTE THE MOLECULAR THICKNESS AT END POINTS OF EACH ROW. JET0950
IM=2                                                 JET0951
XTH(J)=XF(KF)                                     JET0952
TH(J)=0.                                            JET0954
DTH0=NO*SIGMA*DY                                    JET0955
IF(J.EQ.1) GO TO 11                                JET0956
J1=J-1                                             JET0957
DO 1 JJ=1,J1                                       JET0958
XX1=XTH(JJ)                                         JET0959
CALL INTERP(0,IM,KF,XX1,XF,RM1,RMF,RP1,RPF)        JET0960
CALL RFUNC(RM1,RP1,M1,MU1,TETA1)                   JET0961
GOREM=1.D0+G1*M1**2                                 JET0962
DTH=DTH0/GOREM**G6                                  JET0963
TH(JJ)=TH(JJ)+DTH                                   JET0964
1 CONTINUE                                           JET0965
CONTINUE                                           JET0966
RETURN                                              JET0967
END                                                 JET0968

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PLUMES

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SUBROUTINE PLUMES                               JET0969
C SUBROUTINE NUMBER 13                          JET0970
IMPLICIT REAL*8(A-H,L-Z,$)                    JET0971
REAL*4 XPL,YPL                                 JET0972
COMMON /PLUME/XPL(1002,10),YPL(1002)          JET0973
COMMON /IPLUME/KPL,ITYPL(10)                   JET0974
DIMENSION VPL(92)                             JET0975
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET0976
1           TETAF(101),BF(101),                     JET0977
2           XN(101),RMN(101),RPN(101),MN(101),MUN(101),   JET0978
3           TETAN(101),BN(101),XTEMP(101)             JET0979
COMMON/THICKY/XTH(1002),TH(1002)               JET0980
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF            JET0981
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET0982
1           ,XIAPP(101,20),XIF(101,20)              JET0983
COMMON /GAMA/G, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12, G13, G14, G15, JET0984
1           G16,G17,G18,G19,G20                     JET0985
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET0986
1           STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,   JET0987
2           TETSYM,TETLIM,DDY,DYMAX                 JET0988
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1           JET0989
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,      JET0990
1           KF2,IDELEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD    JET0991
COMMON /ROW/YF,YN,DXF,DXN                     JET0992
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET0993
1           RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),   JET0994
2           TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),   JET0995
3           CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),   JET0996
4           MCHARI(92)                            JET0997
COMMON /ICHARA/KCHARP,KCHARM,KCHARO           JET0998
C COMPUTE SPECIAL POINTS AT Y=YN, AND STORE THEM AS JET0999
C (XPL(J,IPL),YPL(J)=YN).                      JET1000
C J IS THE MARCHING INDEX OF YN.                JET1001
C IPL=1,2,...,KPL IS THE "PLUME" INDEX. PRESENTLY KPL.LE.5 JET1002
C VPL(IPL) IS A VALUE DEFINING THE "PLUME" CURVE.       JET1003
C ITYPL(IPL) IS THE TYPE OF CURVE. IT DEFINES CURVES AS FOLLOWS: JET1004
C ITYPL(IPL)=0 DO NOTHING                         JET1005
C ITYPL(IPL)=1 REAL PLUME. IT IS THE BREAKDOWN SURFACE, DEFINED JET1006
C BY A CONSTANT VALUE OF THE BREAKDOWN PARAMETER B.      JET1007
C SET VPL(IPL)=B.                                JET1008

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C ITYPL(IPL)=2 CONSTANT MACH-NUMBER LINE. VPL(IPL)=M.          JET1009
C ITYPL(IPL)=3 A SINGLE STREAMLINE. VPL(IPL) IS SET TO THE EXIT    JET1010
C X-COORDINATE OF THAT STREAMLINE.                                JET1011
C ITYPL(IPL)=4 A SINGLE C+ CHARACTERISTIC LINE STARTING AT THE CORNER. JET1012
C VPL(IPL) IS SET TO THE INDEX KC OF THAT CHARACTERISTIC      JET1013
C LINE.                                                       JET1014
C ITYPL(IPL)=5 A CONSTANT LATERAL (X) OPACITY LINE. VPL(IPL) IS SET JET1015
C TO THE VALUE OF THE (CONSTANT) OPACITY.                         JET1016
C                                                       JET1017
C DEFINE ITYPL(IPL) AND VPL(IPL)                                 JET1018
  KPL=10
  IF(KPL.GT.10) CALL FIN(1301)
  DO 2000 IPL=1,KPL
    GO TO (2001,2002,2003,2004,2005,2006,2007,2008,2009,2010),IPL
2001 ITYPL(IPL)=4
  VPL(IPL)=1
  GO TO 2000
2002 ITYPL(IPL)=4
  VPL(IPL)=KCHARP
  GO TO 2000
2003 ITYPL(IPL)=4
  VPL(IPL)=19
  GO TO 2000
2004 ITYPL(IPL)=4
  VPL(IPL)=31
  GO TO 2000
2005 ITYPL(IPL)=4
  VPL(IPL)=47
  GO TO 2000
2006 ITYPL(IPL)=4
  VPL(IPL)=55
  GO TO 2000
2007 ITYPL(IPL)=1
  VPL(IPL)=0.02D0
  GO TO 2000
2008 ITYPL(IPL)=1
  VPL(IPL)=0.03D0
  GO TO 2000
2009 ITYPL(IPL)=1
  VPL(IPL)=0.05D0
  GO TO 2000
2010 ITYPL(IPL)=1
  VPL(IPL)=0.08D0
  GO TO 2000
2000 CONTINUE
C COMPUTE "PLUME" POINTS AT Y=YN
  DO 1000 IPL=1,KPL
    ITYP=ITYPL(IPL)
    IF(ITYP.EQ.0) GO TO 1000
    GO TO (1,2,3,4,5), ITYP
1  CONTINUE
C BREAKDOWN SURFACE PLUME.
C NOTE THAT DUE TO DIFFERENCE-CENTERING OF GRADIENTS, THE ACCURATE JET1060
C Y-COORDINATE IS 0.5*(YF+YN), RATHER THAN YN. IT CAN BE ADJUSTED JET1061
C IN THE PLOTTING CODE.                                         JET1062
  BO=VPL(IPL)
  XTEMP(1)=XN(1)
  DO 11 I=2,KN
    XTEMP(I)=0.5D0*(XN(I)+XN(I-1))
11  CONTINUE
  I=2
  CALL INTERX(1,I,BO,BN,KN,XB0,XTEMP)
  XPL(J,IPL)=XB0
  GO TO 1001
2  CONTINUE
C FIND BY INTERPOLATION THE X-COORDINATE WHERE M=MPL.           JET1074
  IF(J.GT.1) GO TO 200
  XPL(J,IPL)=XC
  GO TO 1001
200  CONTINUE
  MPL=VPL(IPL)
  I=-KN

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      CALL INTERX(1,I,MPL,MN,KN,XM0,XN)          JET1081
      XPL(J,IPL)=XM0                           JET1082
      GO TO 1001                               JET1083
      3   CONTINUE                               JET1084
C STREAMLINE INTERPOLATION.
      IF(J.GT.1) GO TO 300                      JET1085
      XPL(J,IPL)=VPL(IPL)                      JET1086
      GO TO 1001                               JET1087
 300  CONTINUE                               JET1088
      XSF=XPL(J-1,IPL)                        JET1089
      ISF=2                                    JET1090
      ISN=2                                    JET1091
      CALL INTERP(0,ISF,KF,XSF,XF,RMSF,RMF,RPSF,RPF) JET1092
      CALL RFUNC(RMSF,RPSF,MSF,MUSF,TETASF)     JET1093
      XSN=XSF+DY*DTAN(PAI2-TETASF)            JET1094
      ITER=1                                    JET1095
 301  ITER=ITER+1                          JET1096
      CALL INTERP(1,ISN,KN,XSN,XN,RMSN,RMN,RPSN,RPN) JET1097
      CALL RFUNC(RMSN,RPSN,MSN,MUSN,TETASN)     JET1098
      TETAAV=0.5D0*(TETASF+TETASN)             JET1099
      XSN=XSF+DY*DTAN(PAI2-TETAAV)            JET1100
      IF(ITER.LT.ITER0+2) GO TO 301           JET1101
      XPL(J,IPL)=XSN                         JET1102
      GO TO 1001                               JET1103
      4   CONTINUE                               JET1104
C CHARACTERISTIC LINE.
      KC=IDINT(VPL(IPL)+1.D-5)                JET1105
      IF(J.GT.1) GO TO 41                      JET1106
      XPL(J,IPL)=XCHARF(KC)                  JET1107
      GO TO 1001                               JET1108
 41   CONTINUE                               JET1109
      XPL(J,IPL)=XCHARN(KC)                  JET1110
      IF(CSIGNN(KC).EQ.0.) XPL(J,IPL)=1.E33    JET1111
      GO TO 1001                               JET1112
      5   CONTINUE                               JET1113
C CONSTANT LATERAL (X) OPACITY
      CALL OPACX                            JET1114
      XIC=VPL(IPL)                         JET1115
      DO 51 II=2,KF                         JET1116
      I1=KF-II+1                           JET1117
      I2=I1+1                                JET1118
      XI1=XI(I1,JXI)                      JET1119
      XI2=XI(I2,JXI)                      JET1120
      IF((XIC-XI1)*(XIC-XI2).GT.0.) GO TO 51 JET1121
      F2=(XI2-XIC)/(XI2-XI1)              JET1122
      F1=1.D0-F2                           JET1123
      IF(F1.LT.0.) CALL FIN(1351)          JET1124
      IF(F2.LT.0.) CALL FIN(1352)          JET1125
      XIFC=F2*XF(I1)+F1*XF(I2)           JET1126
      GO TO 52                                JET1127
 51   CONTINUE                               JET1128
      XIFC=1.D30                           JET1129
 52   CONTINUE                               JET1130
      XPL(J,IPL)=XIFC                      JET1131
      GO TO 1001                               JET1132
 1001  CONTINUE                               JET1133
      IF(J.GT.1) GO TO 1002                 JET1134
      YPL(J)=YC                           JET1135
      GO TO 1000                               JET1136
 1002  CONTINUE                               JET1137
      YPL(J)=YN                           JET1138
 1000  CONTINUE                               JET1139
      RETURN                                 JET1140
      END                                   JET1141
      SUBROUTINE GRIDN
C SUBROUTINE NUMBER 14
      IMPLICIT REAL*8(A-H,L-Z,$)          JET1142
      REAL*4 XPL,YPL                      JET1143
      COMMON /PLUME/XPL(1002,10),YPL(1002) JET1144
      COMMON /IPLUME/KPL,ITYPL(10)        JET1145
      COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
      1          TETA(101),BF(101),          JET1146
                                         JET1147
                                         JET1148
                                         JET1149
                                         JET1150
                                         JET1151
                                         JET1152

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GRIDN

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2           XN(101),RMN(101),RPN(101),MNC(101),MUN(101),      JET1153
3           TETAN(101),BN(101),XTEMP(101)                      JET1154
COMMON/THICKY/XTH(1002),TH(1002)                         JET1155
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1156
1           G16,G17,G18,G19,G20                                JET1157
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1158
1           STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,   JET1159
2           TETSYM,TETLIM,DDY,DYMAX                           JET1160
COMMON /STAG/RHOO,NO,PO,TO,A0,MDOT1                      JET1161
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,              JET1162
1           KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD       JET1163
COMMON /ROW/YF,YN,DXF,DXN                                JET1164
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1165
1           RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),    JET1166
2           TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),    JET1167
3           CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),    JET1168
4           MCHARI(92)                                     JET1169

COMMON /ICHARA/KCHARP,KCHARM,KCHARO                      JET1170
C DIVIDE LINE Y=YN INTO KN-1 INTERVALS.                  JET1171
C THE X-GRID IS NON-UNIFORMLY DEFINED AS FOLLOWS:        JET1172
C (1) (XCHARN(I),YCHARN(I)), (XCHARF(I),YCHARF(I)), I=1,2,...,KCHARP, JET1173
C DENOTE NEW AND OLD (FORMER) CHARACTERISTIC (C+) POINTS. LET I=1 JET1174
C AND I=KCHARP CORRESPOND TO THE LEADING AND BOUNDARY JET1175
C CHARACTERISTICS (C+).                                 JET1176
C (2) THE GRID CONSISTS OF TWO SEGMENTS. THE SO-CALLED FLAT SEGMENT JET1177
C IS BETWEEN X=0 AND X=XLEAD=XCHARN(KCLEAD). THE SECOND IS THE JET1178
C FAN SEGMENT. IT IS FROM XLEAD TO XBOUND=XCHARN(KCHARP).        JET1179
C (3) THE FAN SEGMENT IS INITIALLY DIVIDED INTO FRACG*(KF0-1) INTERVALS JET1180
C DEFINED BY THE FAMILY OF C+ CHARACTERISTIC LINES MCHARI(1) TO JET1181
C MCHARI(KCHARP).                                     JET1182
C (4) THE FLAT SEGMENT IS DIVIDED INTO (1-FRACG)*(KF0-1) EQUAL JET1183
C INTERVALS, AS LONG AS THEY ARE NOT SMALLER THAN THE AVERAGE JET1184
C FAN INTERVAL. WHEN THEY ARE, THEIR NUMBER IS REDUCED, BUT NOT JET1185
C BELOW THREE.                                         JET1186
C (5) KCLEAD IS INITIALLY 1. IT IS UPDATED SO THAT THE FLAT SEGMENT JET1187
C IS AT LEAST TWICE THE AVERAGE FAN INTERVAL.          JET1188
ILEADF=ILEAD                                         JET1189
KCLEAD=0                                              JET1190
DO 1 KC=1,KCHARP                                     JET1191
IF(CSIGNN(KC).LT.0.) GO TO 1                         JET1192
KCLEAD=KC                                           JET1193
KFAN=KCHARP-KCLEAD                                    JET1194
XLEAD=XCHARN(KCLEAD)                                JET1195
XBOUND=XCHARN(KCHARP)                                JET1196
DX1=(XBOUND-XLEAD)/DFLOAT(KFAN)                     JET1197
IF(XLEAD/DX1.GT.2.D0) GO TO 11                       JET1198
CONTINUE                                             JET1199
11 CONTINUE                                           JET1200
IF(KCLEAD.EQ. 0) CALL FIN(1401)                      JET1201
IF(KCLEAD.EQ.KCHARP) CALL FIN(1402)                 JET1202
ILEAD=IDINT(XLEAD/DX1)+2                            JET1203
IF(ILEAD+KFAN.GT.KF0) ILEAD=KF0-KFAN               JET1204
ILEAD1=ILEAD-1                                       JET1205
KN=ILEAD+KFAN                                      JET1206
IF(KN.GT.KF0) CALL FIN(1411)                        JET1207
DX=XLEAD/DFLOAT(ILEAD1)                            JET1208
XN(1)=0                                              JET1209
DO 2 I=1,ILEAD1                                     JET1210
XN(I)=XN(1)+DX*DFLOAT(I-1)                         JET1211
CONTINUE                                             JET1212
DO 3 I=ILEAD,KN                                     JET1213
XN(I)=XCHARN(KCLEAD+I-ILEAD)                      JET1214
CONTINUE                                           JET1215
RETURN                                              JET1216
END                                                 JET1217

SUBROUTINE YSTEP
C SUBROUTINE NUMBER 15                               JET1218
IMPLICIT REAL*8(A-H,L-Z,$)                         JET1219
REAL*4 XPL,YPL                                     JET1220
COMMON /PLUME/XPL(1002,10),YPL(1002)                JET1221
COMMON /IPLUME/KPL,ITYPL(10)                         JET1222
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET1223
                                                JET1224

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YSTEP

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1           TETAF(101),BF(101),                                JET1225
2           XN(101),RMN(101),RPN(101),MN(101),MUN(101),      JET1226
3           TETAN(101),BN(101),XTEMP(101)                      JET1227
COMMON/THICKY/XTH(1002),TH(1002)                          JET1228
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1229
1           G16,G17,G18,G19,G20                                JET1230
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1231
1           STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,   JET1232
2           TETSYM,TETLIM,DDY,DYMAX                           JET1233
COMMON /STAG/RHOO,NO,P0,T0,A0,MDOT1                      JET1234
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,               JET1235
1           KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD       JET1236
COMMON /ROW/YF,YN,DXF,DXN                                 JET1237
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1238
1           RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),     JET1239
2           TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),      JET1240
3           CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),      JET1241
4           MCHARI(92)                                     JET1242
COMMON /ICHARA/KCHARP,KCHARM,KCHARO                      JET1243
C COMPUTE NEXT Y-STEP.                                    JET1244
C DYNEXT IS DEFINED AS THE MINIMAL "TRIANGULATION" Y-STEP DYT, OBTAINED JET1245
C BY FORWARD INTERSECTION OF C-,C+ CHARACTERISTICS FROM ADJACENT GRID JET1246
C POINTS X1,X2.                                         JET1247
DYMIN=1.D40                                              JET1248
DO 1 I=3,KF                                             JET1249
X1=XF(I-1)                                              JET1250
X2=XF(I)                                                 JET1251
DX=X2-X1                                              JET1252
TP1=DTAN(TETAF(I-1)-MUF(I-1))                         JET1253
TP2=DTAN(TETAF(I)+MUF(I))                            JET1254
F1=-TP2/(TP1-TP2)                                      JET1255
IF(F1.LE.0.) PRINT 555,I,X1,X2,DX,TP1,TP2,F1          JET1256
555  FORMAT(/1X,'I,X1,X2,DX,TP1,TP2,F1=',I5,6D14.6/) JET1257
IF(F1.LT.0.) CALL FIN(1501)                           JET1258
DYT=F1*DX*TP1                                         JET1259
IF(DYT.LE.0.) CALL FIN(1502)                           JET1260
DYMIN=DMIN1(DYMIN,STAB*DYT)                           JET1261
1           CONTINUE                                     JET1262
DYNEXT=DYMIN                                         JET1263
RETURN                                                 JET1264
END                                                   MOVE JET1265

SUBROUTINE MOVE                                         JET1266
C SUBROUTINE NUMBER 16                                  JET1267
IMPLICIT REAL*8(A-H,L-Z,$)                           JET1268
REAL*4 XPL,YPL                                         JET1269
COMMON /PLUME/XPL(1002,10),YPL(1002)                 JET1270
COMMON /IPLUME/KPL,ITYPL(10)                           JET1271
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET1272
1           TETAF(101),BF(101),                                JET1273
2           XN(101),RMN(101),RPN(101),MN(101),MUN(101),      JET1274
3           TETAN(101),BN(101),XTEMP(101)                      JET1275
COMMON/THICKY/XTH(1002),TH(1002)                      JET1276
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1277
1           G16,G17,G18,G19,G20                                JET1278
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1279
1           STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,   JET1280
2           TETSYM,TETLIM,DDY,DYMAX                           JET1281
COMMON /STAG/RHOO,NO,P0,T0,A0,MDOT1                      JET1282
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,               JET1283
1           KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD       JET1284
COMMON /ROW/YF,YN,DXF,DXN                                 JET1285
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1286
1           RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),     JET1287
2           TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92),      JET1288
3           CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92),      JET1289
4           MCHARI(92)                                     JET1290
COMMON /ICHARA/KCHARP,KCHARM,KCHARO                      JET1291
C STORE NEW LINE (N) IN OLD LINE (F).                   JET1292
KF=KN                                                 JET1293
KF2=2*KF                                              JET1294
YF=YN                                                 JET1295
DO 1 I=1,KN                                         JET1296

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XF(I)=XN(I) JET1297
RMF(I)=RMN(I) JET1298
RPF(I)=RPN(I) JET1299
MF(I)=MN(I) JET1300
MUF(I)=MUN(I) JET1301
TETAF(I)=TETAN(I) JET1302
BF(I)=BN(I) JET1303
1 CONTINUE JET1304
DO 2 KC=1,KCHARO JET1305
IF(CSIGNN(KC).EQ.0.) GO TO 2 JET1306
XCHARF(KC)=XCHARN(KC) JET1307
YCHARF(KC)=YCHARN(KC) JET1308
RMCARF(KC)=RMCARN(KC) JET1309
RPCARF(KC)=RPCARN(KC) JET1310
TCHARF(KC)=TCHARN(KC) JET1311
MUCARF(KC)=MUCARN(KC) JET1312
MCHARF(KC)=MCHARN(KC) JET1313
CSIGNF(KC)=CSIGNN(KC) JET1314
2 CONTINUE JET1315
RETURN JET1316
END JET1317

SUBROUTINE OPACX JET1318
C SUBROUTINE NUMBER 17 JET1319
IMPLICIT REAL*8(A-H,L-Z,$) JET1320
REAL*4 XPL,YPL JET1321
COMMON /PLUME/XPL(1002,10),YPL(1002)
COMMON /IPLUME/KPL,ITYPL(10)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
1 TETAF(101),BF(101), JET1325
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET1326
3 TETAN(101),BN(101),XTEMP(101) JET1327
COMMON/THICKY/XTH(1002),TH(1002) JET1328
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF JET1329
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET1330
1 ,XIAPP(101,20),XIF(101,20) JET1331
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15, JET1332
1 G16,G17,G18,G19,G20 JET1333
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1334
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET1335
2 TETSYM,TETLIM,DDY,DYMAX JET1336
COMMON /STAG/RH00,NO,P0,T0,A0,MDOT1 JET1337
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1338
1 RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92), JET1339
2 TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92), JET1340
3 CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92), JET1341
4 MCHARI(92) JET1342
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET1343
1 KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1344
COMMON /ROW/YF,YN,DXF,DXN JET1345
C COMPUTE X-OPACITY. JET1346
C BEGIN FROM LIMITING CHARACTERISTIC OF AN ASSUMED P.M. FAN. JET1347
C XIO -- THE THICKNESS BETWEEN THE LIMITING CHARACTERISTIC AND THE JET1348
C BOUNDARY CHARACTERISTIC OF THE NUMERICAL COMPUTATION. JET1349
DO 12 I=1,KF0 JET1350
XIF(I,JXI)=XF(I) JET1351
XI(I,JXI)=0. JET1352
XIPM(I,JXI)=0. JET1353
XIGRP(I,JXI)=0. JET1354
XIAPP(I,JXI)=0. JET1355
12 CONTINUE JET1356
IF(J.EQ.1) GO TO 1000 JET1357
PSILIM=TETLIM JET1358
XLIM=XC+(YF-YC)/DTAN(PSILIM) JET1359
XBOUND=XF(KF) JET1360
KPM=10 JET1361
DX=(XLIM-XBOUND)/DFLOAT(KPM) JET1362
SUM=0. JET1363
DO 1 I=1,KPM JET1364
X1=XBOUND+DFLOAT(I-1)*DX JET1365
X2=X1+DX JET1366
PS1=PAI2-DATAN((X1-XC)/(YF-YC)) JET1367
PS2=PAI2-DATAN((X2-XC)/(YF-YC)) JET1368

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OPACX

```

Q1=(PS1-PSILIM)/G5          JET1369
Q2=(PS2-PSILIM)/G5          JET1370
IF(I.EQ.KPM) Q2=1.D-10       JET1371
IF(Q2.LT.0.) CALL FIN(1701)   JET1372
F1=G11*(DSIN(Q1))**2*(2.D0/(G-1.D0)) JET1373
F2=G11*(DSIN(Q2))**2*(2.D0/(G-1.D0)) JET1374
SUM=SUM+DX*(F1+F2)/2.D0        JET1375
1 CONTINUE                   JET1376
XIO=SUM*(N0*SIGMA)           JET1377
C RE-EVALUATE XIO FOR A RING-JET. JET1378
IF(DELTA.EQ.0.) GO TO 14     JET1379
M=MFIN                      JET1380
CALL MFUNC(M,F,ETA,TETA)     JET1381
PSI=TETA+DARSIN(1.D0/M)      JET1382
GOREM=1.D0+G1*M**2           JET1383
GOR=M**2-1.D0                 JET1384
CALL HINTER(M,HM)            JET1385
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1386
1 +G1*HM/2.D0                  JET1387
EVER=SIGMA*N0*YC/(M*DSIN(TETA)*DSIN(PSI)*GOREM**G6) JET1388
GGG=2.D0-DELT0B*(G+1.D0)/2.D0 JET1389
IF(DABS(GGG).GT.1.D-10) GO TO 15 JET1390
PRINT 16, DELT0B,G,GGG        JET1391
16 FORMAT(/1X,'FROM OPACX. GGG NEARLY ZERO. EXPRESSION FOR XIO IS', JET1392
1 1X,'SINGULAR. DELT0B,G,GGG=',3D12.4/) JET1393
CALL FIN(1715)               JET1394
15 CONTINUE                   JET1395
EVER=EVER/GGG                JET1396
XIO=EVER*((YF/YC)**GGG-1.D0)/(YF/YC) JET1397
14 CONTINUE                   JET1398
XI(KF,JXI)=XIO               JET1399
XIPM(KF,JXI)=XIO             JET1400
XIGRP(KF,JXI)=XIO            JET1401
KF1=KF-1                     JET1402
DO 2 II=1,KF1                JET1403
I=KF-II+1                   JET1404
X1=XF(I)                     JET1405
X2=XF(I-1)                   JET1406
DX=X1-X2                     JET1407
F1=1.D0/(1.D0+G1*MF(I )**2)**G6 JET1408
F2=1.D0/(1.D0+G1*MF(I-1)**2)**G6 JET1409
DTNUM=(N0*SIGMA)*DX*(F1+F2)/2.D0 JET1410
XI(I-1,JXI)=XI(I,JXI)+DTNUM   JET1411
XIPM(I-1,JXI)=1.D24           JET1412
XIGRP(I-1,JXI)=1.D24           JET1413
PS1=PAI2-DATAN((X1-XC)/(YF-YC)) JET1414
PS2=PAI2-DATAN((X2-XC)/(YF-YC)) JET1415
IF(PS2.GT.PSI1) GO TO 2       JET1416
Q1=(PS1-PSILIM)/G5            JET1417
Q2=(PS2-PSILIM)/G5            JET1418
IF(Q1.LT.0.) CALL FIN(1711)   JET1419
F1=G11*(DSIN(Q1))**2*(2.D0/(G-1.D0)) JET1420
F2=G11*(DSIN(Q2))**2*(2.D0/(G-1.D0)) JET1421
DTPM=(N0*SIGMA)*DX*(F1+F2)/2.D0 JET1422
XIPM(I-1,JXI)=XIPM(I,JXI)+DTPM   JET1423
DIST1=DSQRT((X1-XC)**2+(YF-YC)**2) JET1424
DIST2=DSQRT((X2-XC)**2+(YF-YC)**2) JET1425
KC1=KCLEAD+I-ILEAD           JET1426
KC2=KC1-1                     JET1427
IF(KC2.LT.KCLEAD) GO TO 21    JET1428
M1=MCHAR1(KC1)                JET1429
M2=MCHAR1(KC2)                JET1430
CALL MATCH(I ,M1,MG1,MOBI1,MABI1) JET1431
CALL MATCH(I-1,M2,MG2,MOBI2,MABI2) JET1432
F1=1.D0/(1.D0+G1*MG1**2)**G6 JET1433
F2=1.D0/(1.D0+G1*MG2**2)**G6 JET1434
DTGRP=(N0*SIGMA)*DX*(F1+F2)/2.D0 JET1435
XIGRP(I-1,JXI)=XIGRP(I,JXI)+DTGRP JET1436
21 CONTINUE                   JET1437
2 CONTINUE                   JET1438
C APPROXIMATE THICKNESS XIAPP(I,JXI). BASED ON CLOSED-FORM INTEGRATION. JET1439
DO 3 I=1,KF                   JET1440

```

```

XIAPP(I,JXI)=1.D24 JET1441
KC=KCLEAD+(I-ILEAD) JET1442
IF(DELTA.EQ.0.) GO TO 3 JET1443
IF(KC.LT.KCLEAD) GO TO 3 JET1444
IF(XF(I).LT.XCHARF(1)) GO TO 3 JET1445
M=MCHARI(KC) JET1446
CALL MFUNC(M,F,ETA,TETA) JET1447
PSI=TETA+DARSIN(1.D0/M) JET1448
GOREM=1.D0+G1*M**2 JET1449
GOR=M**2-1.D0 JET1450
CALL HINTER(M,HM) JET1451
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1452
1 +G15*HM/2.D0 JET1453
EVER=SIGMAXNO*YC/(M*DSIN(TETA)*DSIN(PSI)*GOREM**G6) JET1454
GGG=2.D0-DELT0B*(G+1.D0)/2.D0 JET1455
IF(DABS(GGG).GT.1.D-10) GO TO 25 JET1456
PRINT 26, I,KC,M,DELT0B,G,GGG JET1457
26 FORMAT(1X,'FROM OPACX. GGG NEARLY ZERO. EXPRESSION FOR XIO IS', JET1458
1 1X,'SINGULAR. I,KC,M=',I5,D12.4/ JET1459
2 1X,'DELT0B,G,GGG=',3D12.4/) JET1460
25 CALL FIN(1725) JET1461
CONTINUE JET1462
EVER=EVER/GGG JET1463
XIAPP(I,JXI)=EVER*((YF/YC)**GGG-1.D0)/(YF/YC) JET1464
3 CONTINUE JET1465
1000 CONTINUE JET1466
RETURN JET1467
END JET1468

```

LOADC

```

SUBROUTINE LOADC JET1469
C SUBROUTINE NUMBER 18 JET1470
IMPLICIT REAL*8(A-H,L-Z,$) JET1471
REAL*4 XPL,YPL JET1472
COMMON /PLUME/XPL(1002,10),YPL(1002) JET1473
COMMON /IPLUME/KPL,ITYPL(10) JET1474
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET1475
1 TETAF(101),BF(101), JET1476
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET1477
3 TETAN(101),BN(101),XTEMP(101) JET1478
COMMON/THICKY/XTH(1002),TH(1002) JET1479
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF JET1480
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET1481
1 ,XIAPP(101,20),XIF(101,20) JET1482
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1483
1 G16,G17,G18,G19,G20 JET1484
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1485
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NUO, JET1486
2 TETSYM,TETLIM,DDY,DYMAX JET1487
COMMON /STAG/RHOO,NO,P0,T0,A0,MDOT1 JET1488
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J, JET1489
1 KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1490
COMMON /ROW/YF,YN,DXF,DXN JET1491
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1492
1 RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92), JET1493
2 TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92), JET1494
3 CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92), JET1495
4 MCHARI(92) JET1496
COMMON /ICHARA/KCHARP,KCHARM,KCHARO JET1497
C LOAD FLOW VARIABLES OF GRID POINTS IN THE FAN SEGMENT FROM THE JET1498
C SEMI-INVERSE INTEGRATION (IN SUBR. SEMINV). NOTE THAT GRID POINTS JET1499
C XN(I) WERE ALREADY DETERMINED IN SUBR. GRIDN. JET1500
DO 1 I=ILEAD,KN JET1501
KC=KCLEAD+I-ILEAD JET1502
IF(KC.GT.KCHARP) CALL FIN(1801) JET1503
RMN(I)=RMCARN(KC) JET1504
RPN(I)=RPCARN(KC) JET1505
MN(I)=MCHARN(KC) JET1506
MUN(I)=MUCARN(KC) JET1507
TETAN(I)=TCHARN(KC) JET1508
1 CONTINUE JET1509
RETURN JET1510
END JET1511
DOUBLE PRECISION FUNCTION NUFUNC(M) JET1512

```

NUFUNC

```

C SUBROUTINE NUMBER 19                                JET1513
IMPLICIT REAL*8(A-H,L-Z,$)                          JET1514
REAL*4 XPL,YPL                                      JET1515
COMMON /PLUME/XPL(1002,10),YPL(1002)                JET1516
COMMON /IPLUME/KPL,ITYPL(10)                         JET1517
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET1518
1          TETA(101),BF(101),                           JET1519
2          XNC(101),RMN(101),RPN(101),MN(101),MUN(101), JET1520
3          TETAN(101),BN(101),XTEMP(101)                 JET1521
COMMON/THICKY/XTH(1002),TH(1002)                   JET1522
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF                JET1523
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20) JET1524
1          ,XIAPP(101,20),XIF(101,20)                  JET1525
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1526
1          G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1528
1          STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET1529
2          TETSYM,TETLIM,DDY,DYMAX                     JET1530
COMMON /STAG/RHO0,NO,PO,TO,A0,MDOT1                JET1531
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,         JET1532
1          KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1533
COMMON /ROW/YF,YN,DXF,DXN                           JET1534
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92), JET1535
1          RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92), JET1536
2          TCHARF(92),TCHARN(92),MUCARF(92),MUCARN(92), JET1537
3          CSIGNN(92),CSIGNF(92),MCHARN(92),MCHARF(92), JET1538
4          MCHARI(92)                                 JET1539
COMMON /ICHARA/KCHARP,KCHARM,KCHARO                JET1540
C COMPUTE NU AS FUNCTION OF MACH NUMBER M. NOTE THAT THE P.M. JET1541
C DEFINITION OF NU HAS BEEN MODIFIED BY ADDING A CONSTANT. THE USUAL JET1542
C CHOICE OF THE CONSTANT IS SUCH THAT NU=0 FOR INFINITE M. JET1543
Q=1.D0/DSQRT(M**2-1.D0)                            JET1544
NUFUNC=NU0-(G5*DATAN(G5*Q)-DATAN(Q))              JET1545
RETURN                                                JET1546
END                                                 JET1547
                                         HMSET
SUBROUTINE HMSET                                    JET1548
C SUBROUTINE NUMBER 20                                JET1549
IMPLICIT REAL*8(A-H,L-Z,$)                          JET1550
REAL*8 KAPAOB                                     JET1551
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1552
1          G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1553
1          STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET1554
2          TETSYM,TETLIM,DDY,DYMAX                     JET1555
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J,         JET1556
1          KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1557
COMMON /GRP/DMINV,MHINV(101),HMV(101)               JET1558
COMMON /IGRP/KHM                                    JET1559
COMMON /KHM=51                                     JET1560
C A ROUTINE FOR THE C+ DERIVATIVE DUE TO RING SYMMETRY (GRP). JET1561
KHM=51                                              JET1562
IF(KHM.GT.101) CALL FIN(2001)                      JET1563
MINVO=1.D0/MEXIT                                     JET1564
DMINV=MINVO/DFLOAT(KHM-1)                           JET1565
M=MEXIT                                             JET1566
SUM=0.                                               JET1567
KHM1=KHM-1                                         JET1568
DO 1 I=1,KHM1                                       JET1569
MF=M                                              JET1570
MHINV(I)=MINVO-DFLOAT(I-1)*DMINV                  JET1571
M=1.D0/MHINV(I)                                     JET1572
DM=M-MF                                           JET1573
M1=M-DM                                         JET1574
M2=M-DM/2.D0                                       JET1575
M3=M                                              JET1576
CALL MFUNC(M1,F1,ETA1,TETA1)                      JET1577
CALL MFUNC(M2,F2,ETA2,TETA2)                      JET1578
CALL MFUNC(M3,F3,ETA3,TETA3)                      JET1579
SUM=SUM+DM*(F1+4.D0*F2+F3)/6.D0                  JET1580
ETA=ETA3                                           JET1581
TETA=TETA3                                         JET1582
PSI=TETA+DARSIN(1.D0/M)                           JET1583
NORM=((3.D0-G)/4.D0)*(M**2-1.D0)**0.75D0/        JET1584

```

```

1   (DSIN(PSI)*(1.D0+G1*M**2)**G14)          JET1585
HM=SUM*NORM                                     JET1586
HMV(I)=HM                                      JET1587
GOREM=1.D0+G1*M**2                            JET1588
GOR=M**2-1.D0                                    JET1589
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1590
1   +((G+1.D0)/(2.D0*(3.D0-G)))*HM           JET1591
EPSI0B=DELT0B/DSQRT(GOR)-DSIN(TETA)/(M*DSIN(PSI)) JET1592
KAPA0B=1.D0                                      JET1593
IF(DABS(PAI2-TETA).GT.1.D-6)                   JET1594
1 KAPA0B=DTAN(TETA)*EPSI0B                      JET1595
LAMD0B=EPSI0B-DELT0B*GOREM/(GOR*DSQRT(GOR))    JET1596
PRINT 11,I,M,HM,TETA*DEG,PSI*DEG             JET1597
11 FORMAT(1X,'I,M,HM,TETA,PSI=',I5,5D12.4)      JET1598
PRINT 12,DELT0B,EPSI0B*KAPA0B*LAMD0B*DEG       JET1599
12 FORMAT(1X,'DELT0B,EPSI0B,KAPA0B,LAMD0B=',5X,5D12.4) JET1600
1 CONTINUE                                       JET1601
MHINV(KHM)=0.                                     JET1602
HMV(KHM)=1.D0                                     JET1603
RETURN                                           JET1604
END                                              JET1605

```

MFUNC

```
SUBROUTINE MFUNC(M,F,ETA,TETA)                JET1606
```

```
C SUBROUTINE NUMBER 21                         JET1607
```

```
IMPLICIT REAL*8(A-H,L-Z,$)                    JET1608
```

```
COMMON /GAMA/G1,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1609
```

```
1   G16,G17,G18,G19,G20                        JET1610
```

```
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1611
```

```
1   STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,        JET1612
```

```
2   NUPT1,TETLIM                                JET1613
```

```
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,      JET1614
```

```
1   KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1615
```

```
COMMON /GRP/DMINV,MHINV(101),HMV(101)          JET1616
```

```
C NU=NUFUNC(M)                                  JET1617
```

```
TETA=NUFUNC(MEXIT)+PAI2-NU                      JET1618
```

```
GOREM=1.D0+G1*M**2                            JET1619
```

```
GOR=M**2-1.D0                                    JET1620
```

```
F=(M**2)*(GOREM**G13)*DSIN(TETA)/GOR**1.25D0    JET1621
```

```
GOREM1=1.D0+G1*MEXIT**2                          JET1622
```

```
GOR1=MEXIT**2-1.D0                                JET1623
```

```
ETA=((GOREM/GOREM1)**G14)*((GOR1/GOR)**0.25D0)  JET1624
```

```
RETURN                                            JET1625
```

```
END                                              JET1626
```

```
SUBROUTINE HINTER(M,H)                          JET1627
```

```
C SUBROUTINE NUMBER 22                         JET1628
```

```
IMPLICIT REAL*8(A-H,L-Z,$)                    JET1629
```

```
COMMON /GAMA/G1,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1630
```

```
1   G16,G17,G18,G19,G20                        JET1631
```

```
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1632
```

```
1   STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,        JET1633
```

```
2   TETSYM,TETLIM,DDY,DYMAX                     JET1634
```

```
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,      JET1635
```

```
1   KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1636
```

```
COMMON /GRP/DMINV,MHINV(101),HMV(101)          JET1637
```

```
COMMON /IGRP/KHM                               JET1638
```

```
C COMPUTE H(M) BY INTERPOLATION               JET1639
```

```
MINV=1.D0/M                                    JET1640
```

```
I=KHM-IDINT(MINV/DMINV-1.D-9)-1              JET1641
```

```
IF(I.GE.1.AND.I.LT.KHM) GO TO 1            JET1642
```

```
PRINT 11,I,KHM,M,MEXIT                       JET1643
```

```
11 FORMAT(1X,'I,KHM,M,MEXIT=',2I5,2D14.6/)    JET1644
```

```
CALL FIN(2201)                                 JET1645
```

```
1 CONTINUE                                       JET1646
```

```
F1=(MINV-MHINV(I+1))/DMINV                     JET1647
```

```
F2=1.D0-F1                                      JET1648
```

```
IF(F1.LT.-1.D-9) CALL FIN(2210)                 JET1649
```

```
IF(F2.LT.-1.D-9) CALL FIN(2211)                 JET1650
```

```
H=F1*HMV(I)+F2*HMV(I+1)                        JET1651
```

```
RETURN                                           JET1652
```

```
END                                              JET1653
```

```
SUBROUTINE MATCH(I,M0B,MAB,M0BI,MABI)          JET1654
```

```
C SUBROUTINE NUMBER 23                         JET1655
```

```
C SUBROUTINE NUMBER 23                         JET1656
```

MATCH

```

IMPLICIT REAL*8(A-H,L-Z,$) JET1657
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101), JET1658
1 TETAF(101),BF(101), JET1659
2 XN(101),RMN(101),RPN(101),MN(101),MUN(101), JET1660
3 TETAN(101),BN(101),XTEMP(101) JET1661
COMMON /ROW/YF,YN,DXF,DZN JET1662
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1663
1 G16,G17,G18,G19,G20 JET1664
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT, JET1665
1 STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0, JET1666
2 TETSYM,TETLIM,DDY,DYMAX JET1667
COMMON /IPAR/JMAX,KFO,ITER0,KF,KN,IM,IP,J, JET1668
1 KF2,IDEI,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD JET1669
COMMON /GRP/DMINV,MHINV(101),HMV(101) JET1670
COMMON /IGRP/KHM JET1671
C COMPUTE H(M) AND THE ALFA-DERIVATIVES JET1672
M=MOB JET1673
CALL MFUNC(M,F,ETA,TETA) JET1674
PSI=TETA+DARSIN(1.D0/M) JET1675
CALL HINTER(M,HM) JET1676
GOREM=1.D0+G1*M**2 JET1677
GOR=M**2-1.D0 JET1678
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1679
1 +G15*HM/2.D0 JET1680
FOB=(G7*GOREM)**G2/M JET1681
FAB=FOB*(YF/YC)**DELT0B JET1682
CALL AREA(FOB,MAB) JET1683
C COMPUTE MABI FROM THE INVERSE PROBLEM SOLUTION JET1684
COTAV=(XF(I)-XC)/(YF-YC) JET1685
PSI0=PAI2-DATAN(COTAV) JET1686
EVY=YF*DLOG(YF/YC)/(YF-YC)-1.D0 JET1687
PSIN=PSI0 JET1688
DO 1 ITER=1,50 JET1689
PSI=PSIN JET1690
M=DSQRT(1.D0+G4/DTAN((PSI-TETLIM)/G5)**2) JET1691
M=DMAX1(M,MEXIT) JET1692
CALL HINTER(M,HM) JET1693
CALL MFUNC(M,F,ETA,TETA) JET1694
GOREM=1.D0+G1*M**2 JET1695
GOR=M**2-1.D0 JET1696
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1697
1 +G15*HM/2.D0 JET1698
EPSI0B=DELT0B/DSQRT(GOR)-DSIN(TETA)/(M*DSIN(PSI)) JET1699
LAMDOB=EPSI0B-DELT0B*GOREM/(GOR*DSQRT(GOR)) JET1700
COTN=COTAV+LAMDOB*EVY/DSIN(PSI)**2 JET1701
PSIN=PAI2-DATAN(COTN) JET1702
DPSI=PSIN-PSI JET1703
IF(DABS(DPSI).LT.1.D-9) GO TO 11 JET1704
1 CONTINUE JET1705
PRINT 12,I,ITER,PSI,PSIN,DPSI,M,XF(I),YF,XC,YC JET1706
12 FORMAT(1X,'I,ITER,PSI,PSIN,DPSI,M,XF(I),YF,XC,YC='// JET1707
1 1X,2I4,8D11.3/) JET1708
CALL FIN(2301) JET1709
11 CONTINUE JET1710
C USING MOBI=M AS COMPUTED FROM THE INVERSE PROBLEM, FIND MABI. JET1711
MOBI=M JET1712
M=MOBI JET1713
CALL MFUNC(M,F,ETA,TETA) JET1714
PSI=TETA+DARSIN(1.D0/M) JET1715
CALL HINTER(M,HM) JET1716
GOREM=1.D0+G1*M**2 JET1717
GOR=M**2-1.D0 JET1718
DELT0B=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1719
1 +G15*HM/2.D0 JET1720
FOB=(G7*GOREM)**G2/M JET1721
FAB=FOB*(YF/YC)**DELT0B JET1722
CALL AREA(FAB,MABI) JET1723
RETURN JET1724
END JET1725
SUBROUTINE AREA(F,M) JET1726
C SUBROUTINE NUMBER 24 JET1727
IMPLICIT REAL*8(A-H,L-Z,$) JET1728

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AREA

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COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1729
1      G16,G17,G18,G19,G20                                         JET1730
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT, MFIN,YMAX,DY0,DY,DYNEXT,          JET1731
1      STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,                JET1732
2      TETSYM,TETLIM,DDY,DYMAX                                         JET1733
COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,                           JET1734
1      KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD                      JET1735
COMMON /GRP/DMINV,MMINV(101),HMV(101)                                     JET1736
COMMON /IGRP/KHM                                         JET1737
C COMPUTE MACH NUMBER M FROM AREA RATIO FUNCTION F                      JET1738
C F=((2/(G+1))*(1+(G-1)*M**2))**((G+1)/(2*(G-1))/M                  JET1739
C INITIAL GUESS IS MIN                                                 JET1740
   E1=(F*MEXIT)**(1.D0/G2)/G7                                         JET1741
   E2=(E1-1.D0)/G1                                         JET1742
   E3=DMAX1(E2,MEXIT**2)                                         JET1743
   MIN=DSQRT(E3)                                         JET1744
   EMN=MIN                                         JET1745
DO 1 I=1,100                                         JET1746
   EMO=EMN                                         JET1747
   GOREM=1.D0+G1*EMO**2                                         JET1748
   GOR=EMO**2-1.D0                                         JET1749
   FO=(G7*GOREM)**G2/EMO                                         JET1750
   DF=FO-F                                         JET1751
C123 PRINT 123,I,EMO,EMN,FO,F,DF,GOR,GOREM                         JET1752
FORMAT(1X,'I,EMO,EMN,FO,F,DF,GOR,GOREM=',I5,7D12.4)                 JET1753
   DFDM=FO*GOR/(EMO*GOREM)                                         JET1754
   DMN=DF/DFDM                                         JET1755
   EMN=EMO-DMN                                         JET1756
   EPSEM=DABS(DMN/EMN)                                         JET1757
   IF(EPSEM.LT.1.D-10) GO TO 11                                JET1758
1  CONTINUE                                         JET1759
   CALL FIN(2401)                                         JET1760
11  CONTINUE                                         JET1761
   M=EMN                                         JET1762
   RETURN                                         JET1763
END                                         JET1764

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